October 26, 2007

Mr. Rick Miller
Pavement Management Engineer
Materials and Research Center
Kansas Department of Transportation
2300 SW Van Buren
Topeka, KS 66611-1195
(785) 296-3008 telephone
rick@ksdot.org

Subject: **Rolling Wheel Deflectometer (RWD) Results for the Kansas Department of Transportation (KDOT).** ARA Project No. 16860.

Dear Mr. Miller:

Applied Research Associates (ARA), Inc. appreciates the opportunity to submit the results of RWD testing performed on selected Kansas highways. This report summarizes the RWD device, testing program, and results.

It has been a pleasure for ARA to provide these services to you, and we look forward to your feedback regarding this innovative device. If you have any questions or comments, please feel free to contact us.

Sincerely,

Douglas A. Steele, P.E.
Senior Engineer

William R Vavrik, Ph.D., P.E.
Midwest Division Manager

Attachment

Cc: Mr. Thomsas Van, FHWA
Cc: Daba Shebera, KSU

TRANSPORTATION SECTOR
505 W. UNIVERSITY AVE. ■ CHAMPAIGN, IL 61820-3915
(217) 356-4500 ■ FAX: (217) 356-3088 ■ WWW.ARA.COM/TRANSPORTATION

FINAL REPORT

Rolling Wheel Deflectometer (RWD) Demonstration for the Kansas Department of Transportation (KDOT)

Prepared for:

Kansas Department of Transportation
2300 SW Van Buren
Topeka, KS 66611-1195
Tel. (785) 296-3008

Prepared by:

Applied Research Associates, Inc.
Transportation Sector
100 Trade Centre Dr., Suite 200
Champaign, IL 61820-7322
Tel. (217) 356-4500

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EXECUTIVE SUMMARY

The Rolling Wheel Deflectometer (RWD) is an innovative device to efficiently measure continuous pavement deflections at normal highway speeds. This previously-not-available data presents many potential benefits to pavement managers and highway agencies, mainly by measuring pavement structural response for use in network-level pavement evaluation and management. This report summarizes a pilot study performed for the Kansas Department of Transportation (KDOT).

Testing Program

- Applied Research Associates (ARA), Inc. performed RWD testing on 17 roadways, consisting of U.S., and state routes. The majority of roads included in this study were two-lane asphalt concrete (AC)-surfaced pavements.

- For each road, the RWD measured a continuous deflection profile in the outer wheel path in a single direction. The RWD operated at normal highway speeds, typically ranging from 50 to 65 mph. ARA tested 506 lane-miles over a 3-day period from July 28 to August 1, 2006 (one rest day). All roads were located in the Topeka region and selected by KDOT.

- ARA post-processed raw laser and distance (DMI) data to calculate deflection. A quality control process was followed to remove any non-representative RWD data due to truck and pavement factors, such as excessive truck bouncing at bridge joints. Overall, a negligible amount of data (less than 0.1 percent) was removed.

- RWD deflections averaged over 0.1-mi intervals were plotted for each highway to provide a deflection profile that showed the magnitude and variability of the pavements' structural response, as well as changes in pavement stiffness. A statistical summary was developed to show the mean deflections and representative deflections (i.e., mean plus 2 standard deviations, or 98th percentile deflection) for each road.

- Pavement structure data (i.e., AC thickness) were provided by KDOT for use in normalization of deflection data to temperature.

- In addition, KDOT provided FWD data collected on the test roads for use in comparison to the RWD.

- Finally, ARA tested four full-depth AC test sections on US 75 northbound near Sabetha. RWD deflections on the four sections were compared to FWD and instrument data collected by KDOT and KSU on the same day. Instrument data included pressure, transverse strain, and longitudinal strain measurements.

Findings

- The diverse pavement set produced mean deflections ranging from 5 to 14 mils, with the lower deflections generally occurring on the thicker pavements, while higher deflections were produced on thinner roads, as expected. In general, the RWD deflections were reasonable for the pavement types and conditions tested.

- In addition to calculating mean deflection for each road, ARA determined the Representative Deflection for each section, defined as the mean plus 2 standard deviations (i.e., 98th percentile). This value is more appropriate than just mean deflection as it takes into account structural variability within a section. This is important as it will be the weaker areas (i.e., areas of higher deflection) that show structural distress first. Representative deflections ranged from 9 to 23 mils. Deflections in this range typically correspond to pavements with fair to good structural capacity.

- ARA assigned structural ratings to each road based on their Representative Deflections. This resulted in the following distribution of ratings for the 17 roads: 1 = very good, 5 = good, 8= fair, and 3= poor. The rating criteria selected by ARA are conceptual only, and can be modified by KDOT accordingly.

- RWD and FWD data collected on the same roads compared well to each other. Some of the FWD data had been collected several years before RWD testing, and a few sets of FWD data were discarded, where it was suspected that work may have been performed on the road between the time of FWD and RWD testing. Overall, there was a linear trend between the RWD to FWD correlation.

- The Sabetha full-depth AC test sections showed mean deflections ranging from 8.1 to 16.8 mils. The thickest test section (16 in of AC) produced the lowest deflections, while the thinnest pavement (11 in of AC) resulted in the highest readings. RWD deflections compared very well to FWD measurements made by KDOT on the same day.

- Relationships between RWD deflection and response of the Sabetha test pavements were produced for pressure, longitudinal strain, and horizontal strain. In general, as deflection increases (due mainly to pavement thickness in this case), the pavement responses increase, as well. The relationships developed can be expanded to be very useful for network-level RWD testing, as they would allow for an estimation of critical strains within AC pavements based on RWD deflections.

Other Benefits

- The RWD is capable of good productivity, testing over 500 lane-miles in 3 test days. Productivity is governed primarily by the length and geographic distribution of test sites. In general, KDOT's selection of long (i.e., 10-to 90-mile) contiguous test sections allowed for good productivity on this study.

- The RWD is a safe method for collecting highway structural data, as it does not require lane closures or interruptions to the highway users. The RWD blends with surrounding traffic, operating at prevailing highway speeds for tractor-trailer combinations, typically performed at 50 to 65 mph.

- In addition to deflections, the RWD also collected continuous digital images of each road. With additional effort, the RWD could be enhanced to collect inertial longitudinal profiles for use in calculating the International Roughness Index (IRI). The combination of pavement deflection, condition rating, and IRI would make the RWD a powerful single device for the collection of multiple PMS data types.

ACKNOWLEDGEMENTS

ARA would like to express our appreciation to the FHWA Office of Asset Management for their sponsorship and support of the RWD program. Specifically, we would like to recognize Mr. Thomas Van and Mr. Stephen Gaj for their continued leadership and support. In addition, we are appreciative to Mr. Michael Arasteh (FHWA Baltimore Resource Center) and Mr. Max Grogg (FHWA Iowa Division) for their input and support of the RWD program.

ARA is thankful to the FHWA Kansas Division office, KDOT, and Kansas State University (KSU) for their assistance in coordinating this pilot study. Specifically, we would like to recognize Mr. Rick Miller (KDOT), Dr. Daba Shebara (KSU), and Dr. Stefan Romanoski (KSU) for their assistance in coordinating and performing this study.

INTRODUCTION

The Rolling Wheel Deflectometer (RWD) is an innovative device for the efficient, high-speed determination of highway pavement structural response. The current prototype was developed jointly by the Federal Highway Administration (FHWA) Office of Asset Management and Applied Research Associates (ARA), Inc. It uses four triangulation lasers mounted beneath the bed of a semi-trailer to measure a continuous pavement deflection profile when loaded by the trailer's 18-kip single axle load. The system has undergone extensive field testing, including pilot studies for numerous state highway agencies, including Texas, Indiana, Virginia, California, and Iowa DOTs. Field testing has verified the RWD's capability to measure pavement deflections at highway speeds. Currently, ARA is enhancing and improving the device to make it available for commercial data collection services.

In July 2006, ARA performed a field demonstration for the Kansas Department of Transportation (KDOT). This report details the testing program and RWD results.

Figure 1. SR 31 through Burlingame.

RWD DESCRIPTION

Equipment

The RWD is comprised of a set of four triangulation lasers attached to an aluminum beam mounted beneath a custom designed 53-ft trailer. The trailer is sufficiently long to isolate the deflection basin produced by the RWD trailer's 18-kip, dual tire, single-axle from deflections produced by the RWD tractor. Figure 2 shows an overview of the RWD truck, trailer, and laser mounting beam. In addition, the natural frequency of the trailer's suspension of 1.45 to 1.8 Hz is low enough that it does not couple with the high-frequency vibration of the 25.5-ft aluminum beam used to support the lasers. The beam uses a curved extension to pass under and between the dual tires, placing the rearmost laser approximately 6 inches rear of the axle centerline and 7 inches above the roadway surface, as shown in figure 2. The wheels have been spaced a safe distance from the laser and beam using custom lugs and a spacer.

Figure 2. Overview of the RWD and a close-up of laser D between the dual tires.

Measurement Methodology

The RWD utilizes a "spatially coincident" methodology for measuring pavement deflection. Three lasers placed forward of the loaded axle are used to define the unloaded pavement surface profile and a fourth laser (D) placed between the dual tires measures the deflected pavement surface. Deflection is calculated by comparing the undeflected pavement surface with the deflected pavement profile at the same location. This method was originally developed by the Transportation and Road Research Laboratory (TRRL) and furthered by Dr. Milton Harr at Purdue University.

At 55 mph, the RWD's 2-kHz lasers take readings approximately every 0.5 in, resulting in extremely large data sets. To make the data set manageable and to reduce the random error of individual readings, data are averaged over an interval suitable for pavement management purposes, typically 0.1-mi (528-ft). At normal highway speeds, a 0.1-mi average contains approximately 60,000 individual laser readings.

TESTING PROGRAM

ARA performed testing from July 28 to August 1, 2006 on roads selected by KDOT. The roads consisted primarily of two-lane state and U.S. routes, and all pavements were constructed of asphalt concrete (AC). Testing was performed in a single direction and referenced using the reference marker system posted in the field. Table 1 summarizes the roads tested. Pavement structure information (i.e., AC thickness was provided by KDOT. A total of 506 lane-miles were tested over 3 days.

In addition, ARA tested the four AC test sections located on U.S. 75 near Sabetha. In this case, the RWD made 15 passes over the approximately 1.5-mi long test section. KDOT and KSU collected FWD and pavement instrument data (i.e., strain and pressure) simultaneous to RWD testing.

The RWD was operated by two people—a driver and an operator. During data collection the operator entered event markers corresponding to bridges, changes in pavement surface type, and zones of significant acceleration/deceleration. RWD data was referenced to KDOT's mile marker system, which was clearly marked for all roads. Event markers are used during data processing for removal of outlier data resulting from localized anomalies. In addition to deflection data, the RWD also records continuous digital images and GPS coordinates for each road. In general, the RWD tested at normal highway speeds (i.e., 50 to 65 mph), whenever conditions permitted.

Figure 3 shows a spatial distribution of the test roads, as recorded by the RWD's GPS.

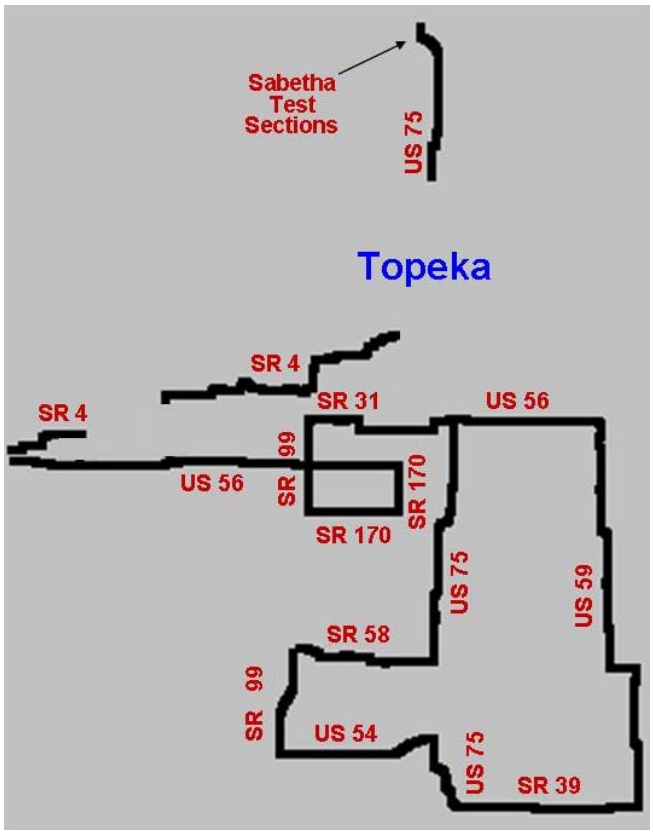


Figure 3. Kansas test roads.

Table 1. Summary of the test roads.

Road	Section	Direction	From	To	Begin MM	End MM	Length, mi
SR 4	A	WB	I-70	SR 177	321	270	51
SR 4	B	WB	SR 149	US 77	249	237	12
US 56	A	EB	US 77	SR 99	327	374	47
SR 99	A	SB	US 56	SR 170	127	118	9
SR 170		EB/NB	SR 99	US 56	0	22	22
US 56	B	WB	SR 170	SR 99	388	374	14
SR 99	B	NB	US 56	SR 31	127	136	9
SR 31		EB	SR 99	Burlingame	0	15	15
US 56	C	EB	Burlingame	US 59	396	427	31
US 59		SB	US 56	SR 39	142	55	87
SR 39		WB	US 59	US 75	39	16	23
US 75	A	NB	SR 39	US 54	59	75	16
US 54		WB	US 75	SR 99	315	290	25
SR 99	C	NB	US 54	SR 58	65	85	20
SR 58		EB	SR 99	US 75	2	25	23
US 75	B	NB	SR 58	US 56	90	138	48
US 75	C	NB	No. of Holton	US 36	190	214	24
US 75	Sabetha	NB	US 36	Exit to Sabetha	216	218	2

DATA PROCESSING AND FILTERING

Data were processed in the office using proprietary RWD software. The software processes the raw RWD files to calculate and display the following parameters per sample unit (0.1-mi):

- RWD deflection and deflection deviation
- Truck speed and speed deviation.
- Pavement surface temperature.
- Linear referencing based on the Distance Measuring Instrument (DMI), GPS, and physical mile markers.
- Event markers, such as bridges, intersections, or other references.

A typical RWD raw data file of 40-mi length (approximately 1 Gb in size) is reduced to an HTML output file of minimal size, making the data set easily viewable and manageable.

The following sections present the quality control process followed to ensure valid RWD results. This process is used to eliminate outlier data due to either truck or pavement factors (e.g., excessive truck bouncing due to bridge joints) from the data set. Typically, only a very small percentage of the data is removed (e.g., less than 0.1 percent).

Truck Speed and Speed Variation

Figure 4 shows the average truck speed for SR 4 westbound from SR 149 to US 77 (Herington). This road presented typical speed variations due to climbing hills and negotiating horizontal curves, as well as the acceleration and deceleration zones at the start/stop of the test run. Variations in this range are not great enough to have a significant effect on the resultant deflection. Figure 5 displays the speed deviation within a 0.1-mi interval. As expected, outliers (i.e., deviations greater than 2 mph) corresponding to the above events can be seen.

Significant accelerating and decelerating of the RWD may cause excessive bouncing of the trailer, resulting in invalid laser readings at isolated locations. When this happens, the RWD deflections are reviewed to determine whether they have been influenced by the truck's bouncing. In this particular case, the truck speed deviations resulted in the elimination of a very small amount of effected data (i.e., less than 0.1 percent).

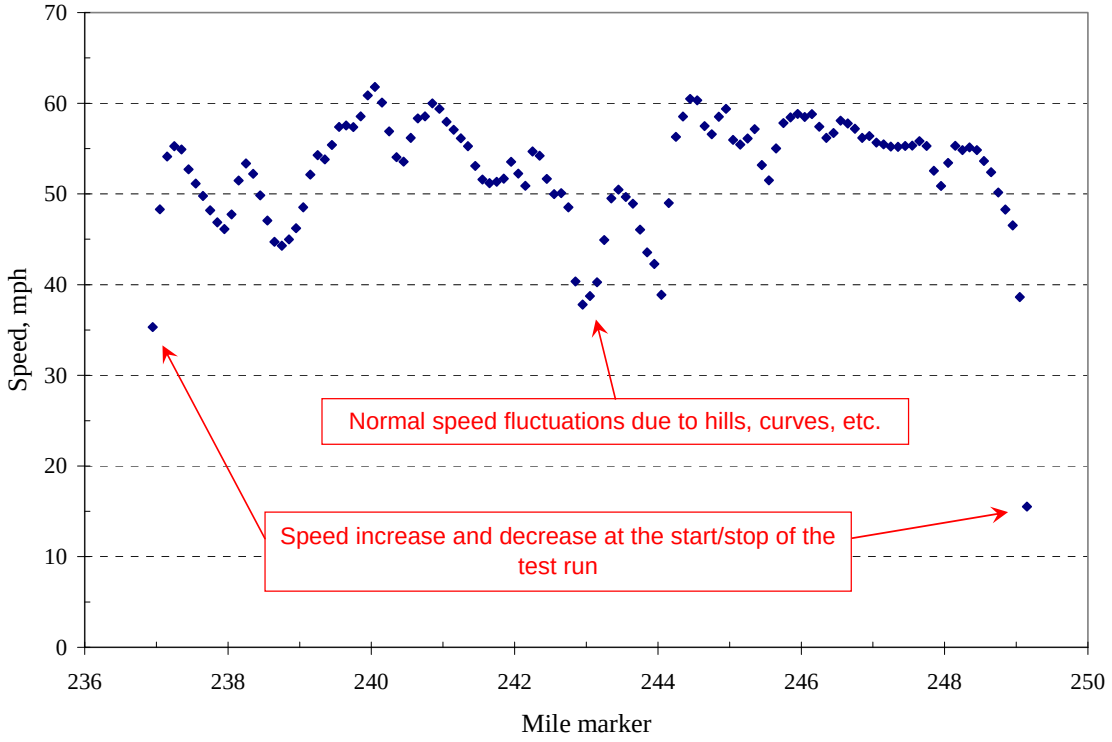


Figure 4. Average truck speed per 0.1-mi interval—SR 4, SR 149 to U.S. 77 (Herington).

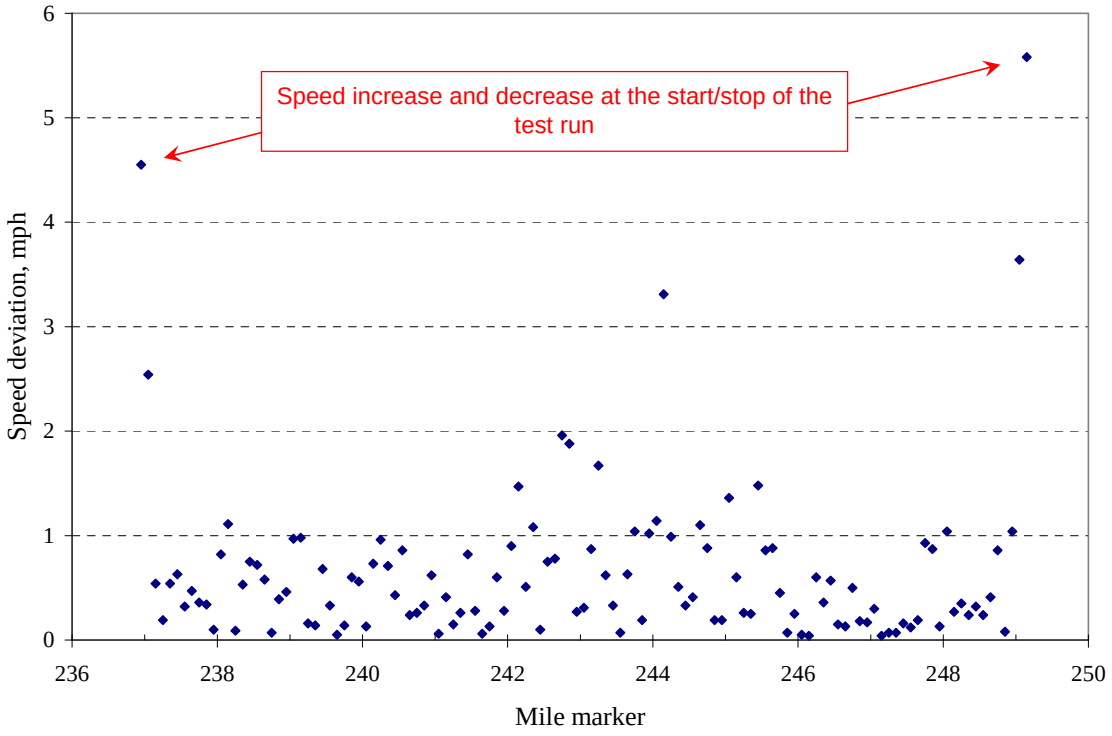


Figure 5. Truck speed deviation per 0.1-mi interval— SR 4, SR 149 to U.S. 77 (Herington).

Pavement Surface Temperature

The RWD collects pavement surface temperatures using an infrared thermometer. These temperatures, in conjunction with air temperature and AC layer thickness, are used to adjust the field deflections to a standard temperature of 68 ºF. The BELS3 method is used to predict the AC mid-depth temperature and the AASHTO 1993 method is used to correct the RWD maximum deflection, based on the predicted AC temperature.

Bridges and Intersections

Finally, deflections were reviewed with respect to pertinent events that were recorded in the data file through the use of markers. These events include bridges, changes in pavement type, areas of significant braking or acceleration, and other discrete events that may have affected isolated deflection readings. In cases where localized deflections were determined to coincide to the noted events, they were removed from the data set.

RWD DEFLECTION RESULTS

This chapter presents sample RWD deflection profiles for several Kansas highways, followed by a statistical summary of all the roads tested. Detailed profiles for all roads are displayed in appendix A. Figures in this chapter show average RWD deflections calculated at 0.1-mi intervals and normalized to a standard temperature of 68 ºF. The representative RWD deflection (i.e., mean plus 2 standard deviations) is shown as well. This corresponds to the 98th percentile (meaning 98 percent of the data is lower than this value) and it is considered more representative of expected pavement structural capacity than the mean RWD deflection itself, as it takes into account pavement variability. In other words, the weaker pavement areas (i.e., areas of high deflection) are expected to show structural deterioration first.

AC in Good Condition on US 56—Low and Uniform Deflections

Figure 6 presents the RWD results and a digital image taken on US 56 between Herington and Council Grove. Overall, this pavement is in good condition with low amounts of cracking. The AC thicknesses along this road range from 8.1 to 14.5 in. Overall, deflections ranged from 5 to 15 mils with an average of approximately 7 mils. A relatively thicker section of 14.5-in AC produced lower deflections between mileposts 342 and 352. The representative deflection (i.e., mean plus 2 standard deviations) of this section was 8 mils, compared to the adjacent 11.5-in AC section, which produced a representative deflection of 12.5 mils. Both of these sections indicate good structural capacity and are expected to have good structural performance for many years.

AC in Fair Condition on SR 58—Medium and Variable Deflections

Figure 7 shows the RWD deflections and the conditions of SR 58 from Madison to US 75. Pavement thicknesses on SR 58 range from 5 to 8 in of AC and the road is in fair condition with significant amounts of transverse and longitudinal cracking. The distress on SR 58 is reflected in the higher variability in RWD deflections, which range from approximately 6 to 20 mils. The representative deflection of SR 58 is 17.1 mils, which reflects the high variability due to accumulated distress. RWD deflections on SR 58 are higher compared to US 56, due to its thinner pavement structure.

AC in Poor Condition on SR 39—High and Variable Deflections

The RWD deflection profile and an image of typical distress on SR 39 are presented in figure 8. The pavements visual condition indicates that it has low remaining structural capacity, as evidenced by its high degree of alligator cracking. Deflections are high and variable on SR 39, ranging from 7 to 27 mils with an approximate mean of 14 mils. SR 39 presents two distinct pavement sections—an area of very high and variable deflections between mileposts 15 and 26, and a section of relatively lower deflections from milepost 26 to 39. The high and variable deflections result in a representative deflection of 24.8 mils, and this is due to the thin AC layer (4.9 in of AC) and high degree of alligator cracking. The remaining section has slightly higher AC thicknesses, ranging from 6.3 to 9 in, and a comparatively lower representative deflection of 17.4 mils.

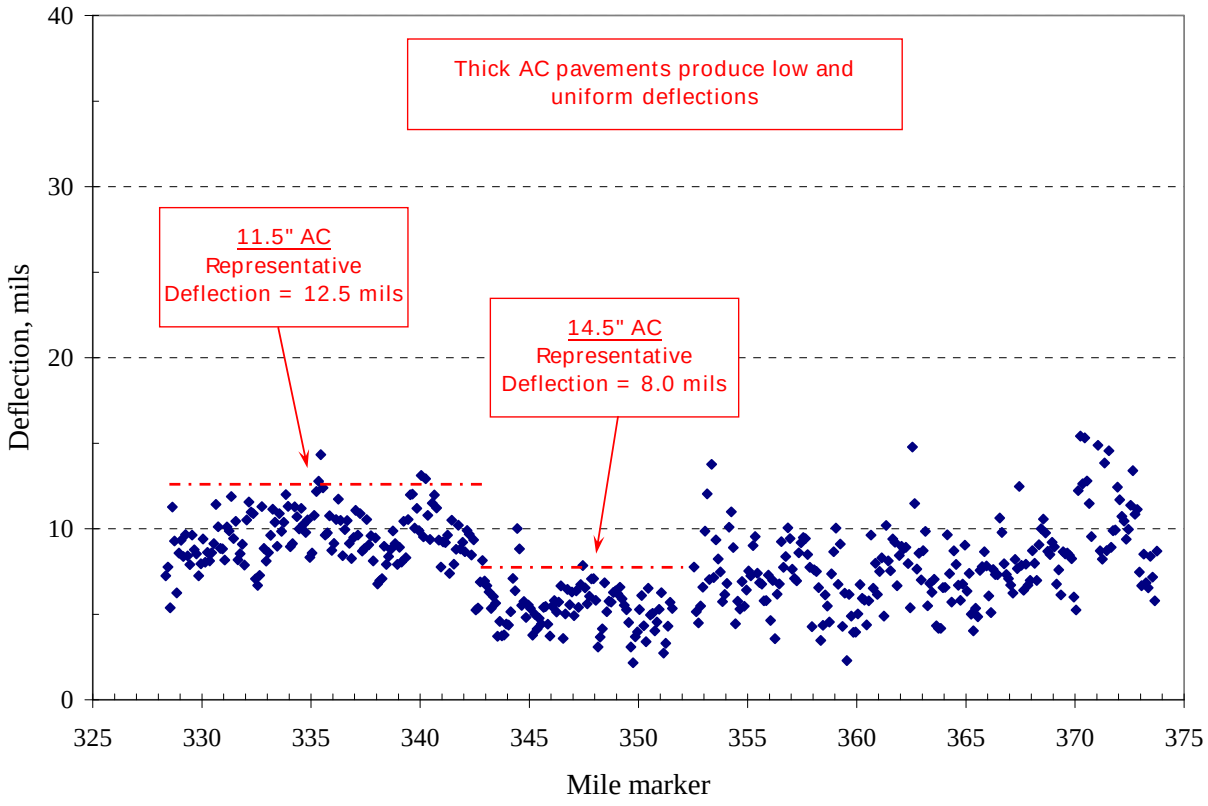


Figure 6. US 56—eastbound. Low and uniform deflections indicate good uniformity and structural capacity due to the thick AC layers.

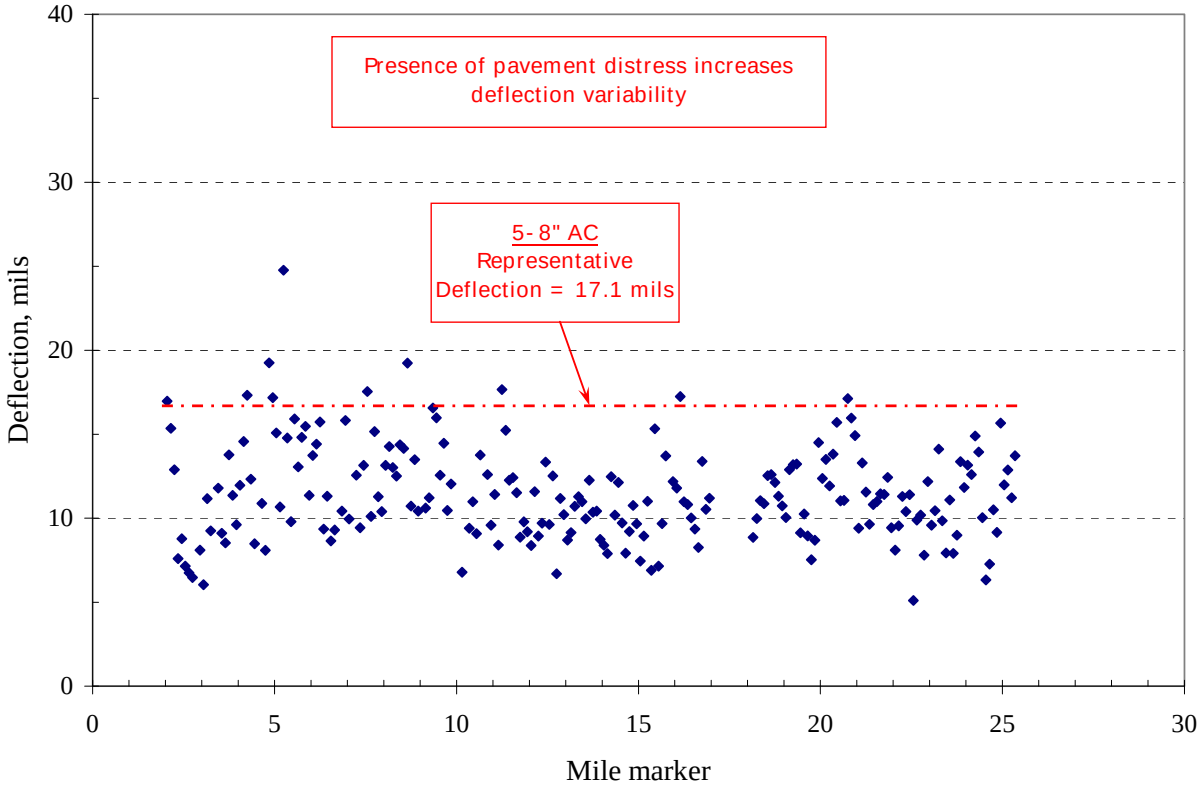


Figure 7. SR 58—eastbound. Deflection variability increases as pavement distress accumulates. Deflections are higher than US 56 due to the relatively thinner AC pavement thicknesses.

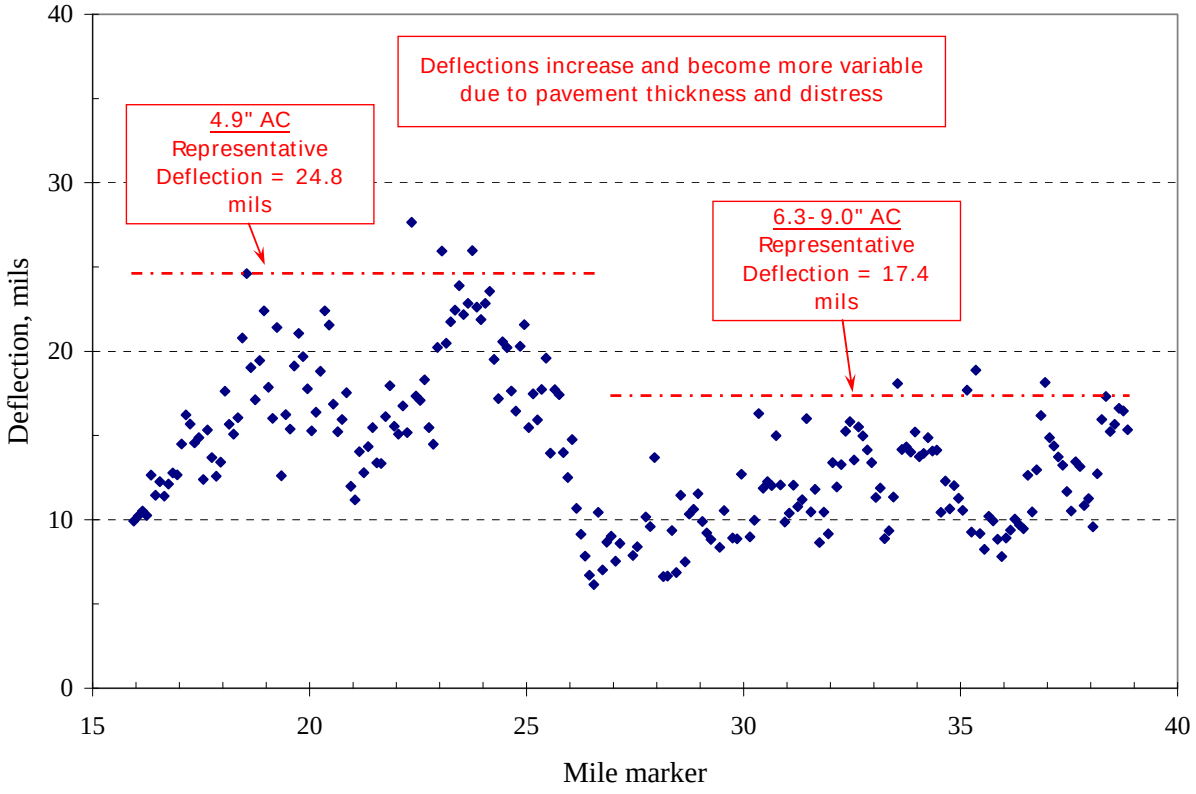


Figure 8. SR 39—westbound. A pavement with little structural remaining life, as evidenced by its poor condition. Pavement deflections in this area were high and variable.

Statistical Summary

Figure 9 presents a statistical summary for all 17 roads tested. For each section, the mean deflection and a range representing +/- 2 standard deviations is displayed. Therefore, the higher the mean value, the weaker the pavement structure. Likewise, the wider the vertical band, the higher the deflection variability within the section. In general, it is desirable to have pavements with low deflections and good uniformity (i.e., low standard deviations). The data show that mean deflections ranged from 5 to 14 mils, with the lower deflections generally occurring on the thicker pavements and the higher, more variable deflections occurring on the thinner pavements, as expected.

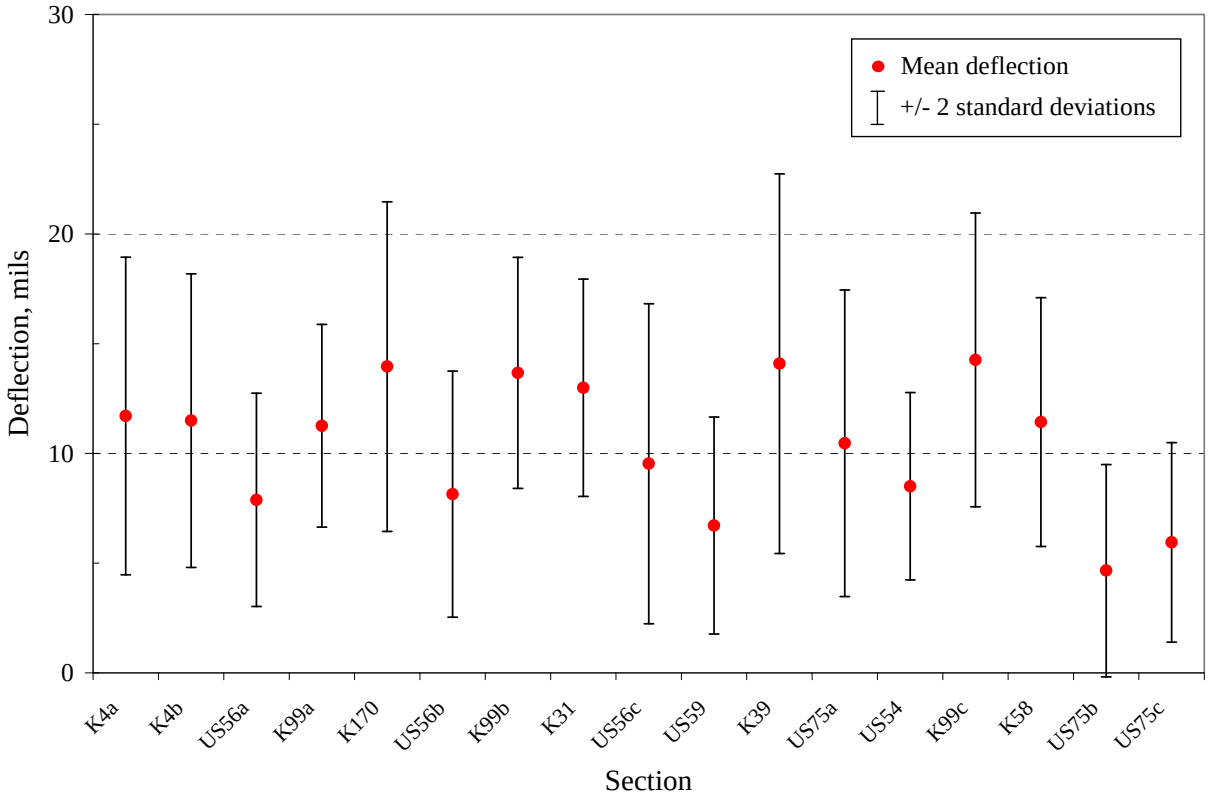


Figure 9. Diverse pavement conditions produced a wide range of deflections and variability.

From a pavement performance point of view, the upper limit of pavement deflections is actually more indicative of expected performance than mean values, as the weaker pavement areas are expected to show structural distress first. Therefore, by defining the section's representative deflection as its mean plus 2 standard deviations (i.e., the 98th percentile), section variability is also taken into account. Figure 10 displays the 17 pavement sections ordered by their representative deflection, lowest to highest. The values range from 9 to 23 mils. Subjective ratings describing the structural capacity of each deflection level (e.g., excellent to very poor) have been assigned to each deflection increment of 5 mils.

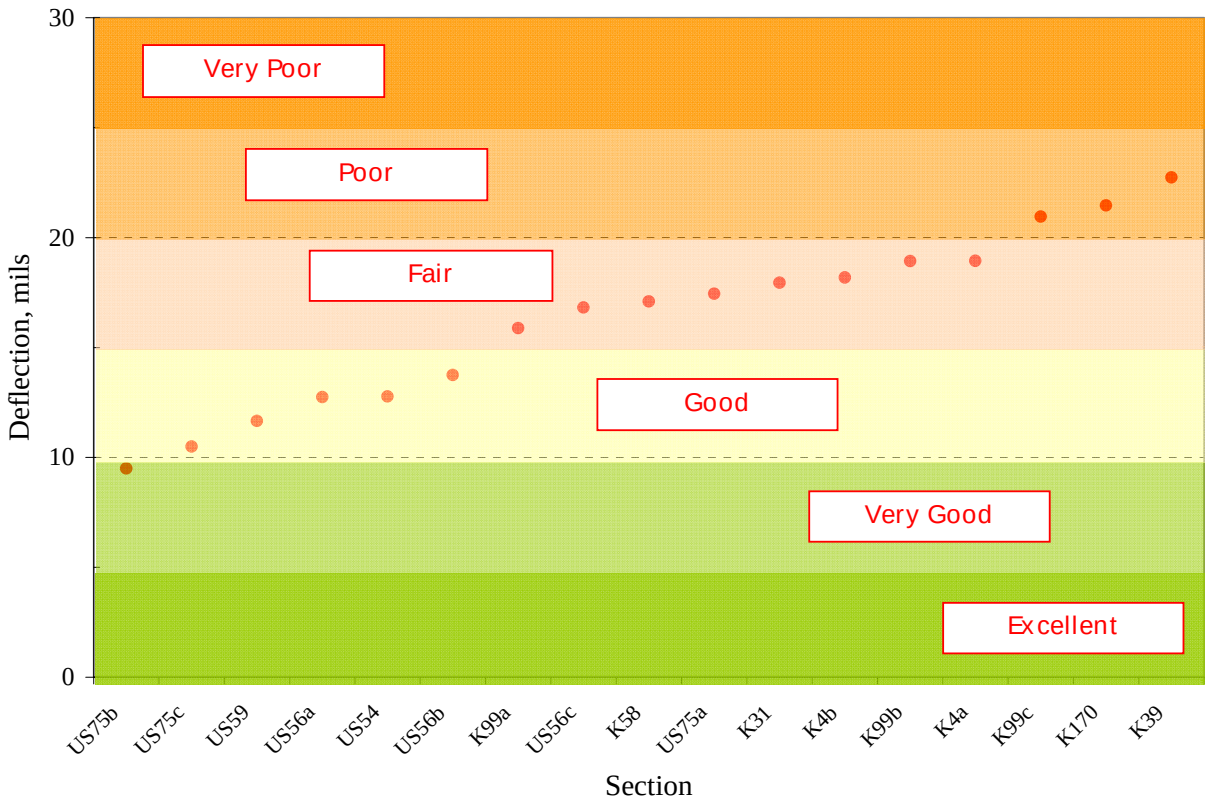


Figure 10. The structural capacity of each section can be characterized by its representative deflection (i.e., mean deflection plus 2 standard deviations).

Comparison to FWD Data

KDOT provided FWD data for the test roads for comparison to the RWD results. The data were collected as part of KDOT's routine FWD testing program, and included results from 1998 to 2006. The data were collected using multiple FWD devices and during different times of the year. Temperature data included in the FWD files were used to normalize deflections to 68 ºF. AC thickness data provided by KDOT were used in the temperature correction procedure.

Figures 11 to 13 present FWD and RWD results for SR 31, SR 170, and US 59. Results for all roads included in this study are presented in appendix A. FWD data were typically collected at 500-ft intervals, while RWD data is an average over 528-ft (i.e., 0.1-mi). Overall, the FWD and RWD showed very similar trends for each road. While it is not expected that the two devices will produce exact profiles for a given road due to inherent differences, they should produce similar trends. For example, as deflections from one device increase, they should also increase from the other. It should be noted that several outlier points were eliminated where large differences between FWD and RWD results existed, as it is believed that work may have been performed between the time of FWD testing and when RWD data was collected.

Figure 14 shows a correlation of mean values between the RWD and FWD for 21 pavement sections. Several roads had multiple FWD sections; therefore, a separate mean value was calculated for each individual section. The results show a linear trend between the two devices and overall a good correlation.

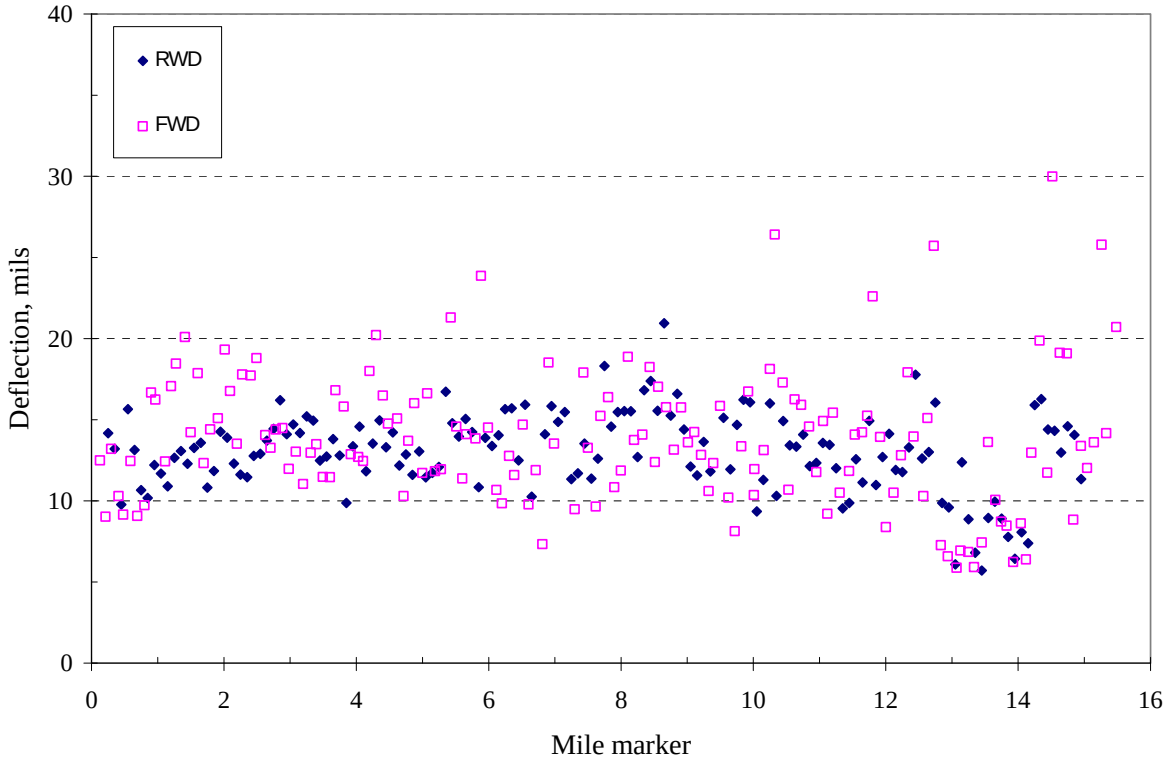


Figure 11. SR 31, SR 99 to Burlingame—eastbound.

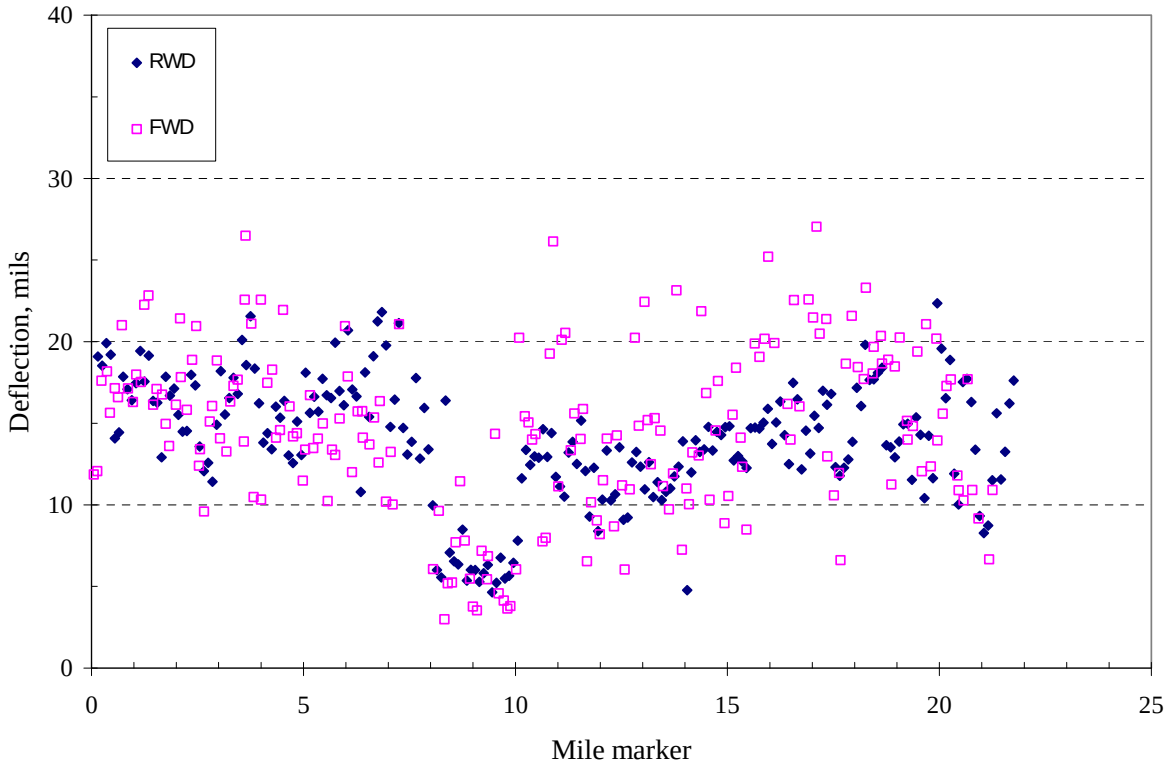


Figure 12. SR 170, SR 99 to Osage City—east and northbound.

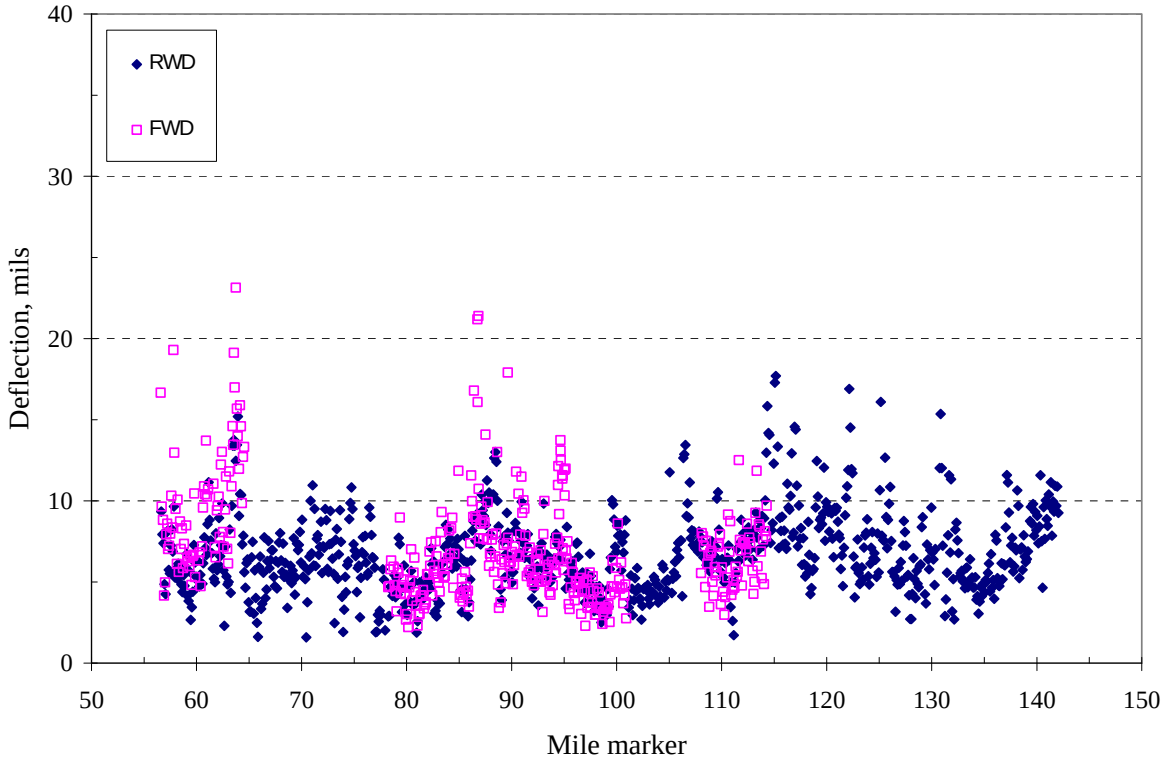


Figure 13. US 59, US 56 to SR 39—southbound.

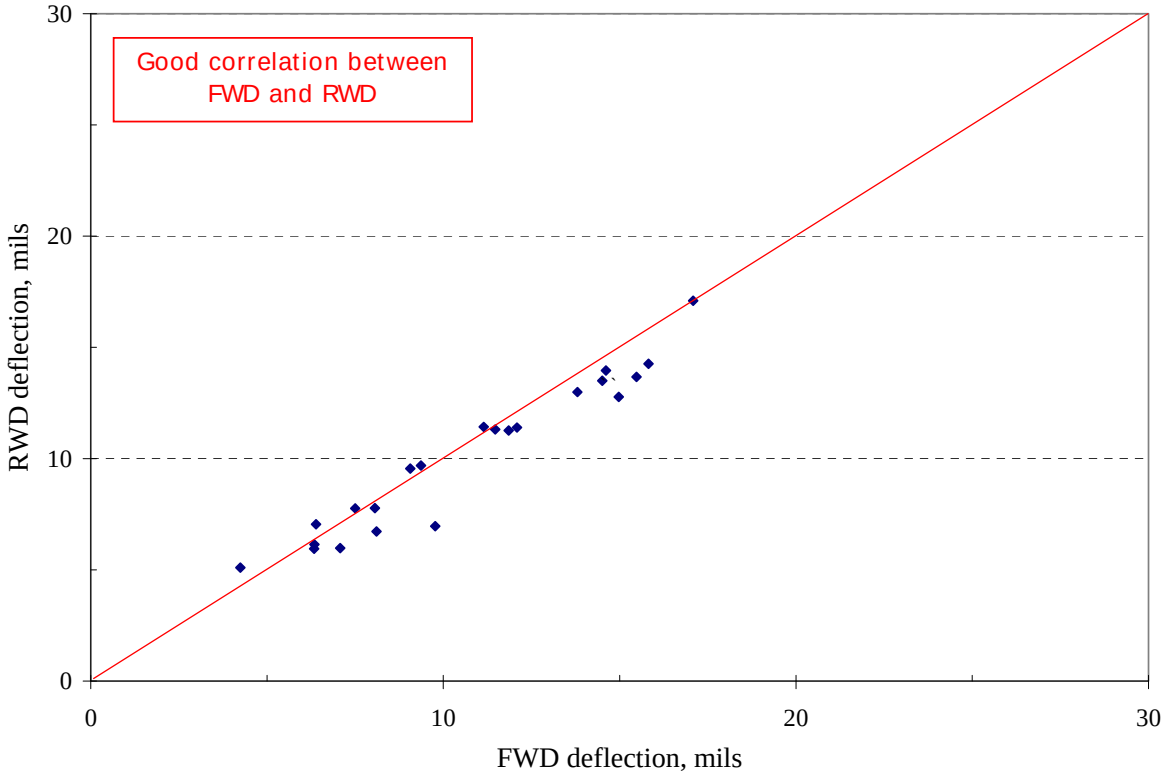


Figure 14. RWD/FWD comparison—mean values for 21 individual sections.

RWD RESULTS—SABETHA TEST SECTIONS

Test Section Layout

KDOT has four full-depth AC test sections on US 75 near Sabetha. The test pavements are in the northbound lane, beginning at 1,193 ft north of mile marker 216. The test sections have been instrumented with strain and pressure gauges, which are operated by KSU. Figure 15 shows the spatial layout of the four test sections, while table 2 presents their locations, as referenced to the milepost 16 marker posted in the field. Figure 16 summarizes the pavement layer types and thicknesses.

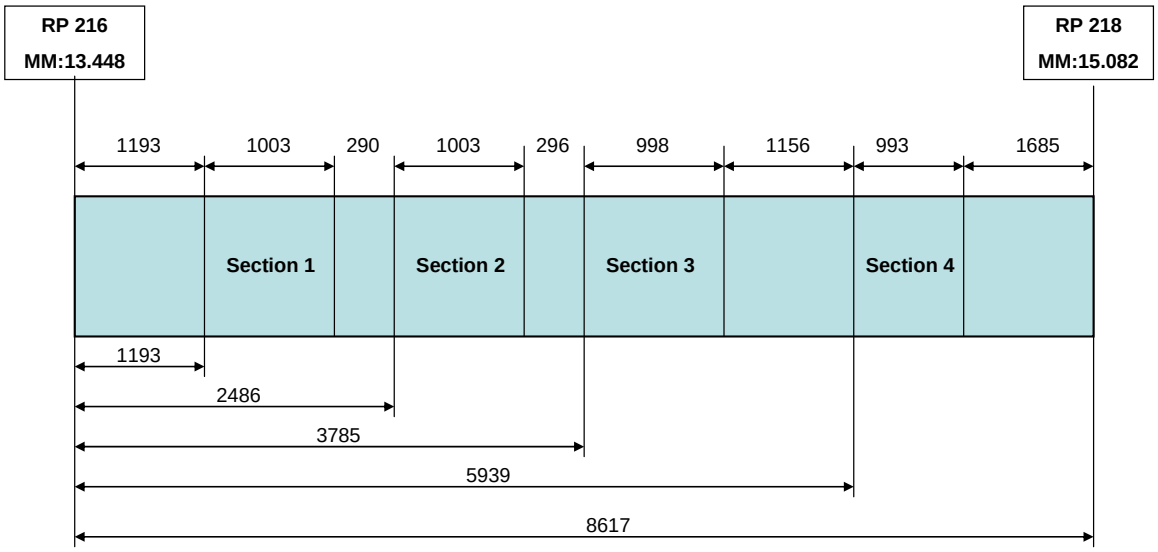


Figure 15. Layout of the four full-depth AC test sections on US 75 near Sabetha.

Table 2. Location of test sections, as referenced to mile marker 216.

Event	Distance from Mile Marker 216, ft	Distance from Mile Marker 216, mi	Milepost referenced to Mile Marker 216	Equivalent County Milepost
Mile Marker 216	0	0	216.000	13.448
Section 1 – Start	1,193	0.226	216.226	13.674
Section 1 – End	2,196	0.416	216.416	13.864
Section 2 – Begin	2,487	0.471	216.471	13.919
Section 2 – End	3,490	0.661	216.661	14.109
Section 3 – Begin	3,786	0.717	216.717	14.165
Mile Marker 217	4,298	0.814	216.814	14.262
Section 3– End	4,784	0.906	216.906	14.354
Section 4 – Begin	5,940	1.125	217.125	14.573
Section 4 – End	6,933	1.313	217.313	14.761
Mile Marker 218	12,429	2.354	218.354	15.802

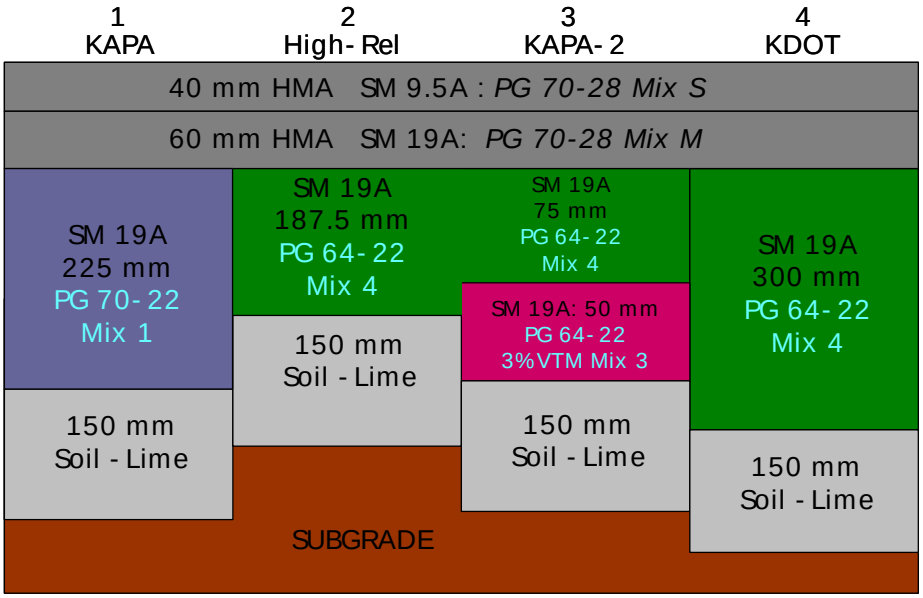


Figure 16. Pavement structures of the four test pavements.

Test Plan

ARA collected RWD data on the Sabetha test sections on August 1, 2006. We made sixteen test passes (15 northbound and 1 southbound) simultaneous to KSU collecting pressure and strain data. During the day, KDOT also performed FWD testing on the same sections. Due to time constraints and the similarity in pavement structures between sections 1 and 3, gauge data was not collected on section 3. Table 3 summarizes the test program. Figure 17 shows the instrument data collection system prepared for testing.

Table 3. Summary of Sabetha test program.

RWD Test Pass	Time hh:mm	Pavement Surface Temperature, ºF	Section Measured with Instruments	AC Mid-Depth Temperature of Section Tested, ºF
1	10:49	110.3	1	97
2	11:05	111.6		
3	RWD tested the southbound lane			
4	11:25	115.0		
5	11:39	117.3		
6	11:54	119.4		
7	12:33	123.7	2	108
8	12:55	122.8		
9	13:13	124.5		
10	13:29	127.2		
11	13:49	128.8		
12	14:27	129.8	3	105
13	14:41	131.0		
14	14:56	128.9		
15	15:11	130.6		
16	15:25	131.3		

Figure 17. Section 1 prepared for instrument data collection.

RWD and FWD Results

Figure 18 shows the RWD deflections for 15 test runs over the four test sections. Each point in the figure represents an average deflection over a 52.8-ft (0.01-mi) interval. Given the RWD's average speed of 50 mph, this corresponds to approximately 1,400 individual deflection readings per 52.8-ft average. The results show RWD deflections ranged from approximately 5 to 23 mils along the length of the test road. In terms of repeatability, the deflections from individual RWD runs agreed within approximately +/- 2 mils of the mean of all 15 runs. A slight increase in deflection during the day is noted due to increasing pavement temperatures.

Figure 19 shows the mean deflection of all 15 RWD test runs vs. FWD data collected by KDOT on the same day. The data show a very good agreement between FWD and RWD deflections. It should be noted that each RWD test point represents a 52.8-ft average, where as the FWD data is a discrete point collected every 50 ft. Therefore, slightly less variability is expected in the RWD data relative to the FWD, due to averaging.

Figure 19 also displays the AC test section boundaries, based on location data provided by KDOT. Interestingly, the section boundaries don't necessarily coincide with sections of uniform pavement deflections, such as in the case of section 1, which shows deflections increasing from approximately 8 to 18 mils within the same section. Assuming that the test sections have been correctly located in the field, this would indicate that the section was constructed with high variability. In other cases, such as sections 3 and 4, both RWD and FWD deflections are very uniform throughout the test section.

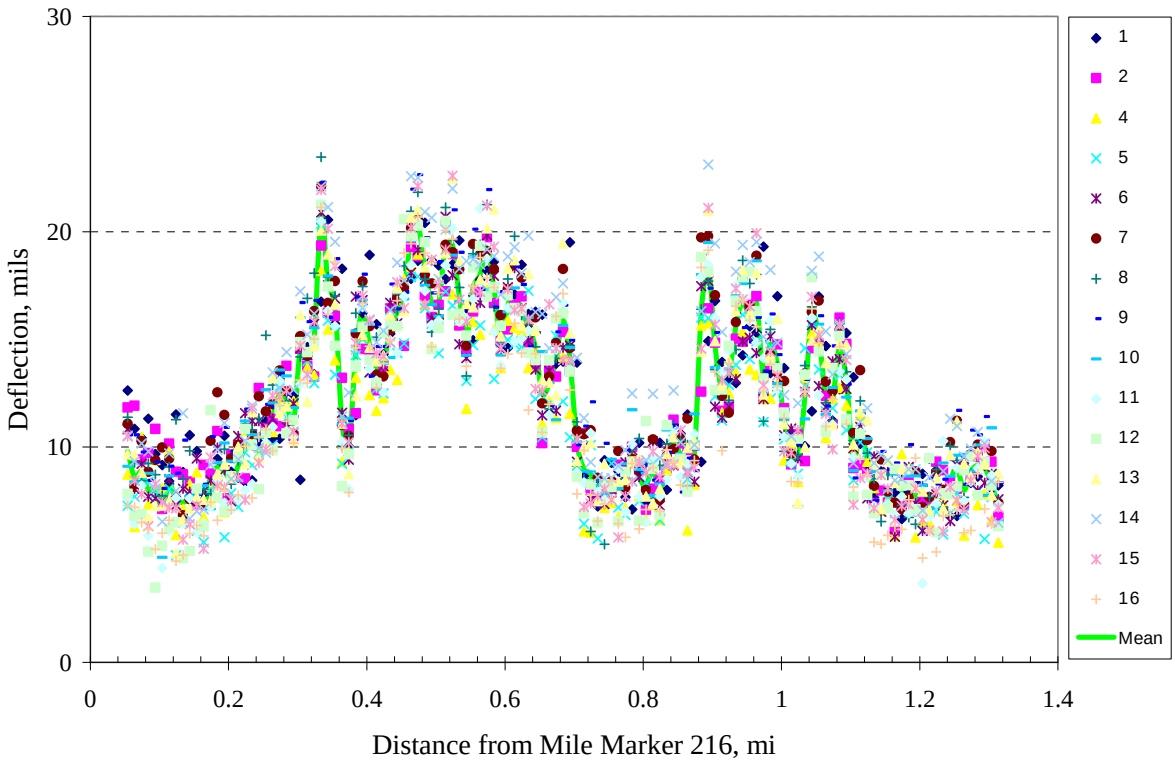


Figure 18. Repeatability of RWD measurements for 15 runs.

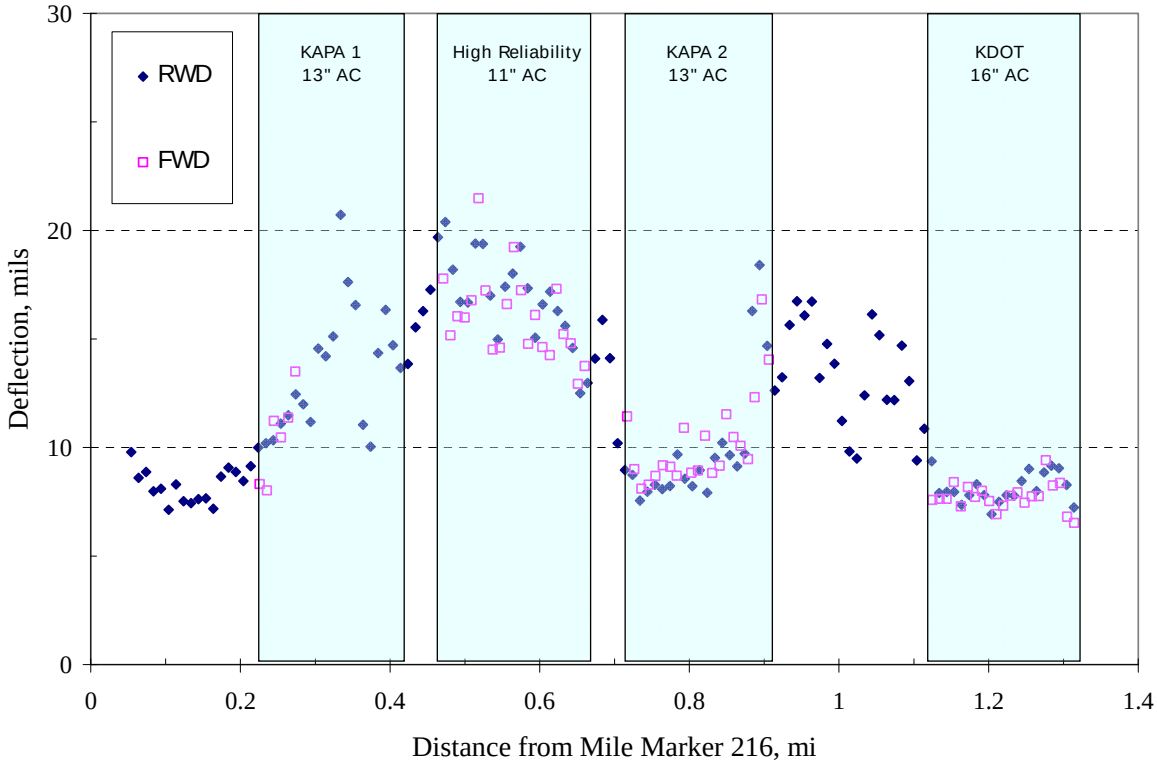


Figure 19. Mean RWD deflection of 15 runs vs. FWD deflections.

Pressure and Strain Results

The Sabetha test sections have gauges for pressure, longitudinal strain, and transverse strain located at the bottom of the AC layer (i.e., between the AC and lime-treated soil layers). Each test section has multiple gauges, with half of the sensors located in the right vehicle wheel path, and the other half located 6 in to the right. KSU collected instrument data on test sections 1, 2, and 4 for five passes of the RWD on each section. In addition, they monitored AC layer temperatures, the averages of which are presented in table 3 above.

Figure 20 shows a sample data trace for transverse strain. Important features of the data trace have been labeled, including (1) the maximum strain due to the RWD's front axle, (3) the maximum strain due to the RWD's tandem axle, and (5) the maximum strain due to the RWD's 18-kip single axle. Appendix C presents tables for the complete set of instrument data collected for all 15 test runs from all the gauges. Table 4 summarizes the maximum values for the locations in the data traces corresponding to the RWD's 18-kip single axle. The results are shown graphically in figure 21.

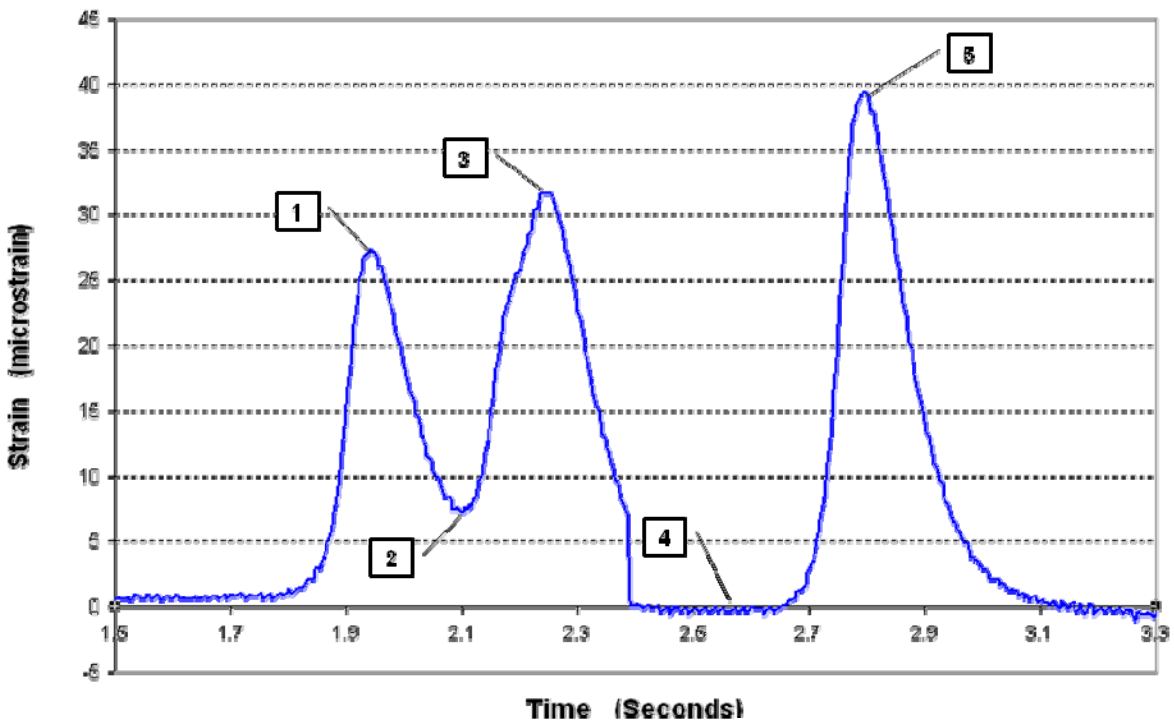


Figure 20. Sample transverse strain trace.

Table 4. Summary of maximum pressure and strains produced by the RWD's 18-kip single axle.

Section	RWD Deflection, mils	Maximum Horizontal Strain, microstrain	Maximum Longitudinal Strain, microstrain	Maximum Pressure, psi
1	13.4	42.2	23.2	1.5
2	16.8	60.2	29.8	2.1
4	8.1	27.0	14.6	1.0

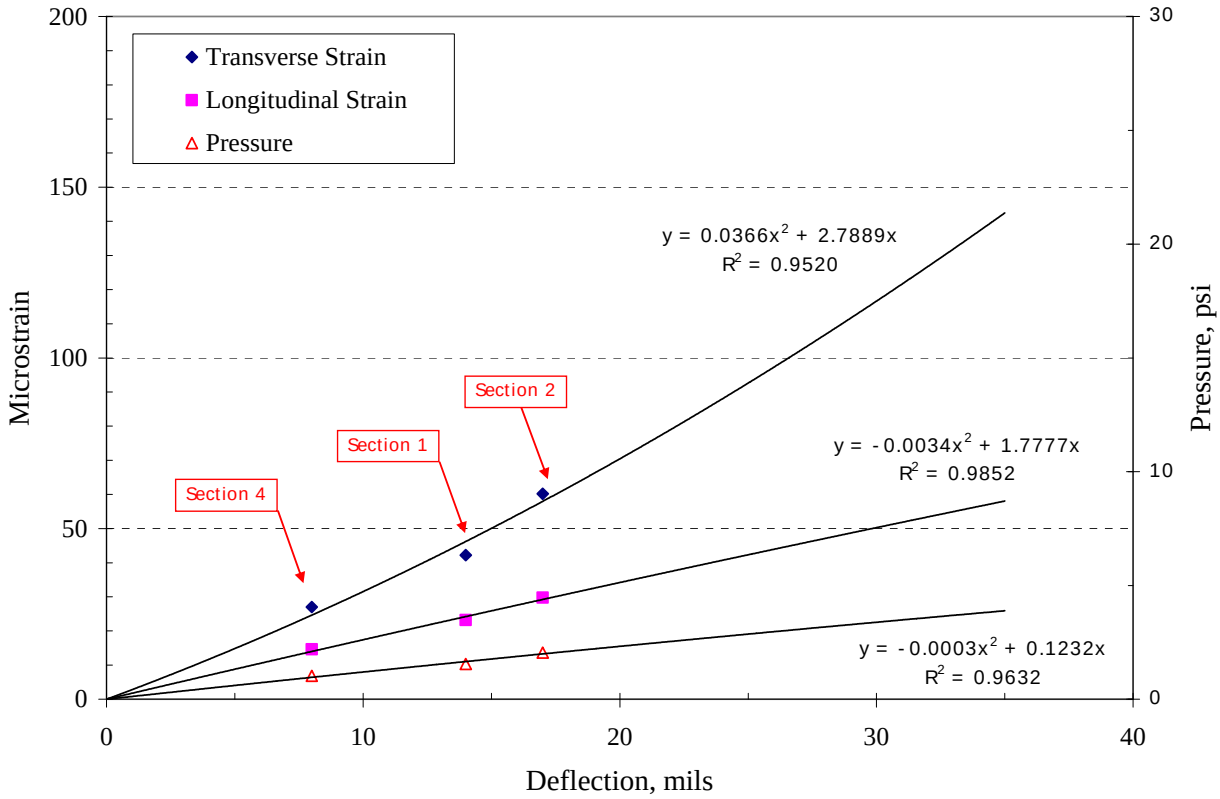


Figure 21. Pavement responses to the RWD's 18-kip axle for three sections.

The results show that as pavement deflection increases that pavement responses, including pressure, horizontal strain, and longitudinal strain, increase as well. In this case, the difference in deflection for each section is due mainly to the difference in pavement thickness. For example, the thickest section (section 4) consists of 16 in of AC and it produced the lowest deflection, of 8.1 mils. The thinnest pavement section (section 2) is constructed of 11 in of AC and produced the highest deflection, 16.8 mils. Likewise, the pavement responses (pressure and strain) produced by the RWD in each section for the same trend as deflection. The higher the deflection, the higher the pressure, strain, and so on. It should be noted that the measured strains are all in the reasonable range for pavements of this thickness. Furthermore, the fit of the best-fit polynomials drawn through the data points is very good.

Figure 21 can be a valuable resource to use in future implementation of the RWD, as it is a direct correlation between RWD deflection and resultant strain. With further expansion, it may be possible to predict critical strains produced by the RWD based on its deflection, for use in large-scale testing.

POTENTIAL USES OF RWD DATA

The RWD provides an efficient means of collecting continuous pavement deflections over a large number of roads, thereby providing pavement structural capacity data not previously available for network-level evaluation and management. As this data has become available, the methods and techniques to use this information in pavement management are also being developed. Several manners of incorporating RWD data into pavement management practices include:

- **Treatment matrices**: This was recently performed on an RWD-based pavement management implementation for Champaign County, IL. RWD data were used in conjunction with visual condition ratings to determine when pavement maintenance and rehabilitation should be performed and appropriate strategies for individual pavement sections (for example, maintenance, surface treatments, overlays, or reconstruction).

- **Pavement preservation:** There is interest from state agencies in using the RWD to identify which roads are suitable candidates for pavement preservation (i.e., maintenance and surface treatments), as opposed to those that require structural improvement. Obviously, if a road lacks structural adequacy, then pavement preservation is not an effective expenditure of funds. The RWD could be used to establish threshold deflection values for when pavement preservation is appropriate, given a specific traffic level.

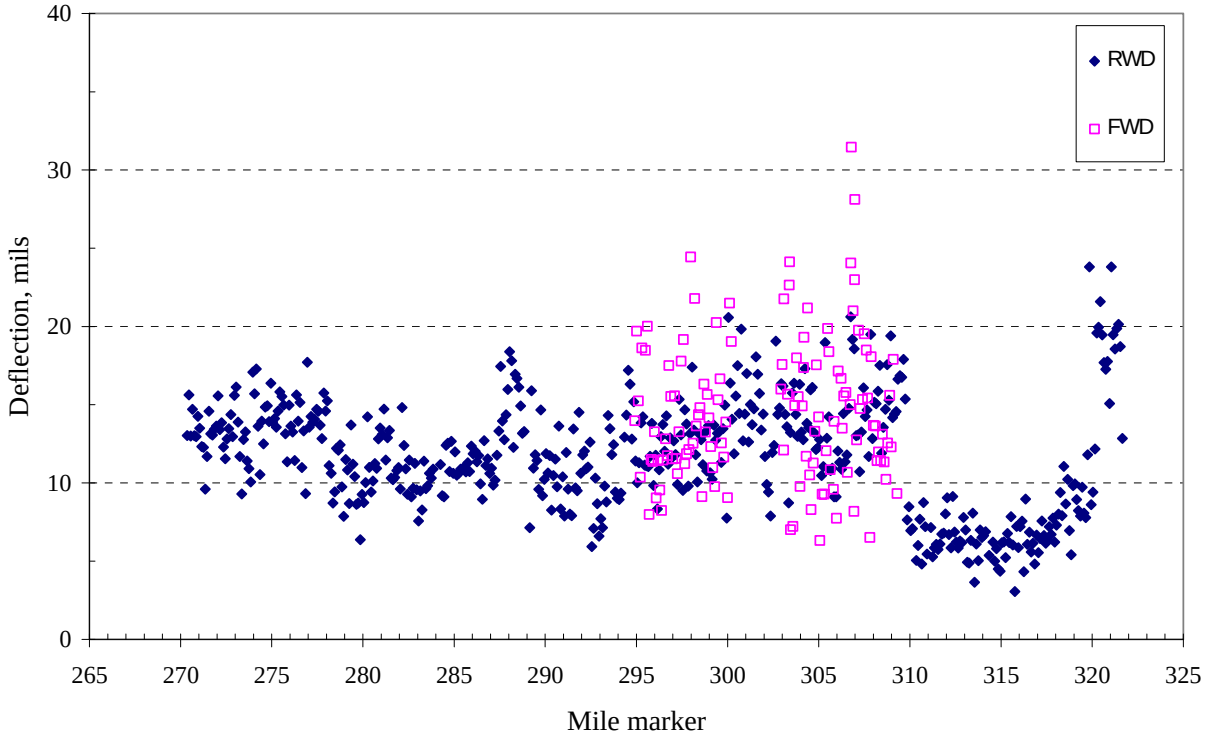
- **RWD-based structural ratings:** Structural ratings can be applied to different deflection levels to describe a road's structural capacity. For example, deflections from 0 to 10 mils, 10 to 20 mils, and 20 to 30 mils represent pavements with High, Medium, and Low structural capacities, respectively. These ratings could be customized for each agency and other factors, such as traffic level.

The data collected as part of this study, along with KDOT's pavement management experience, present an excellent opportunity to develop these methodologies.

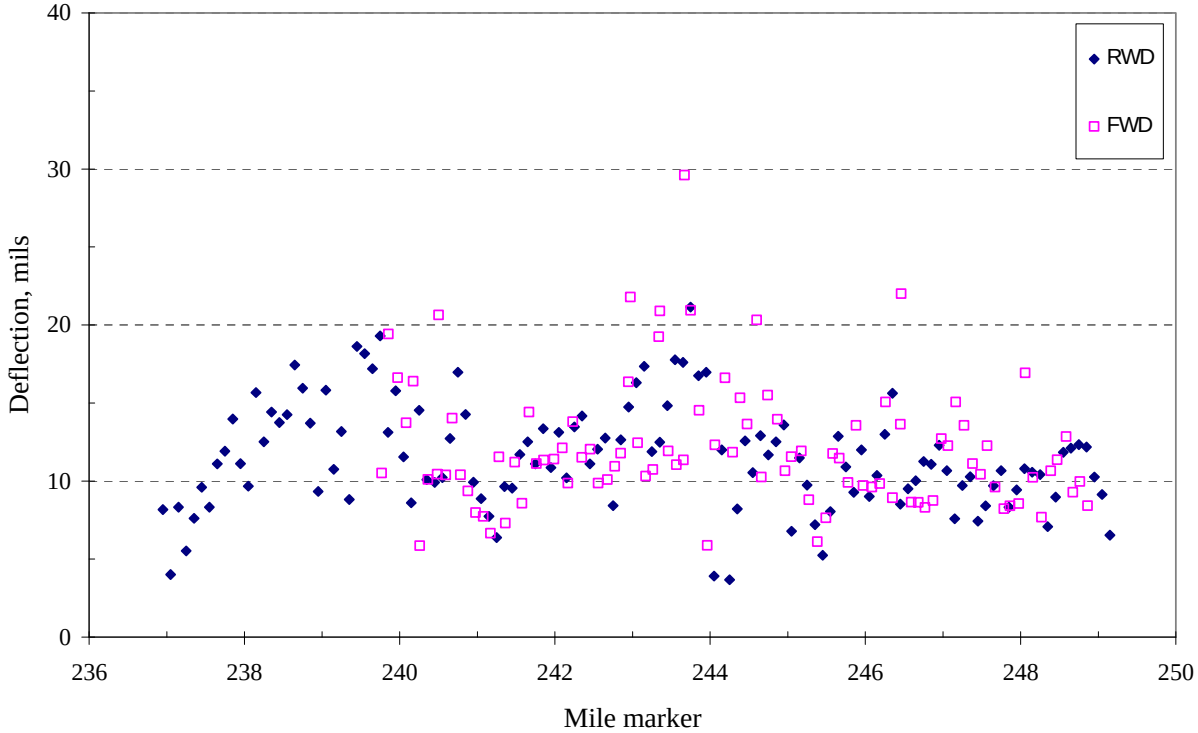
APPENDIX A

RWD Deflection Profiles

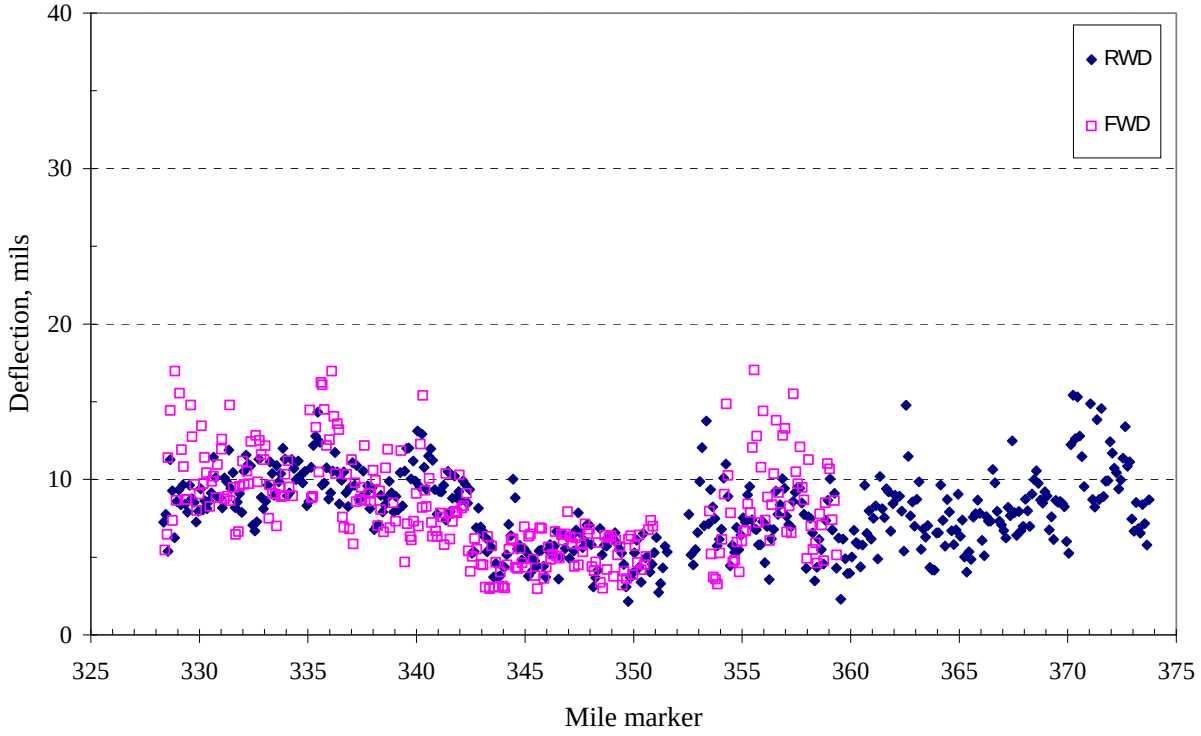
K 4.
I-70 to K 177 - westbound.



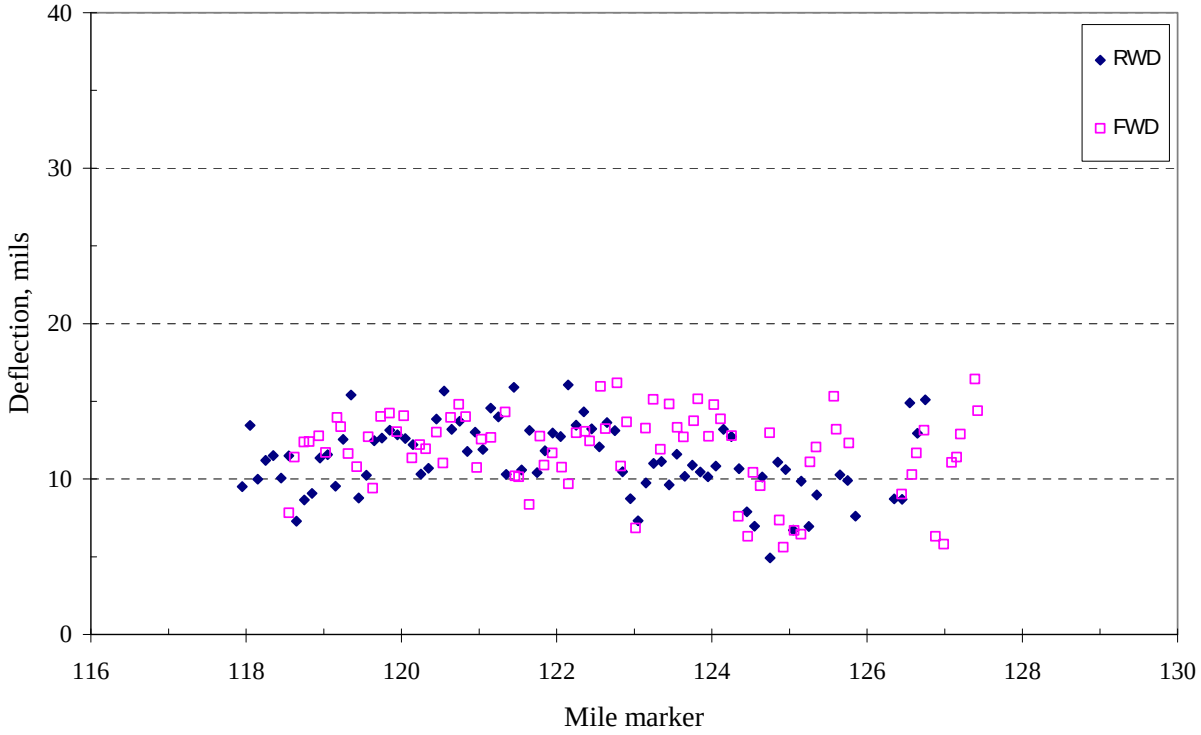
K 4.
K 149 to US 77 - westbound.



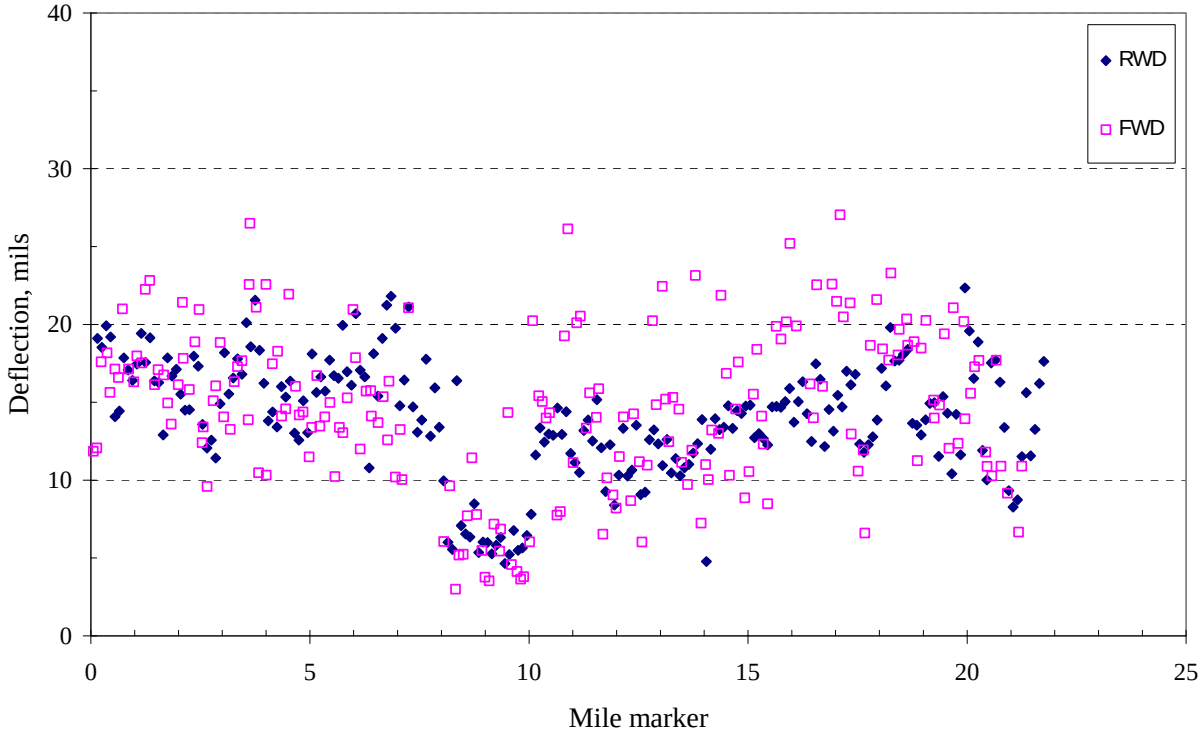
US 56.
US 77 to K 99 - eastbound.



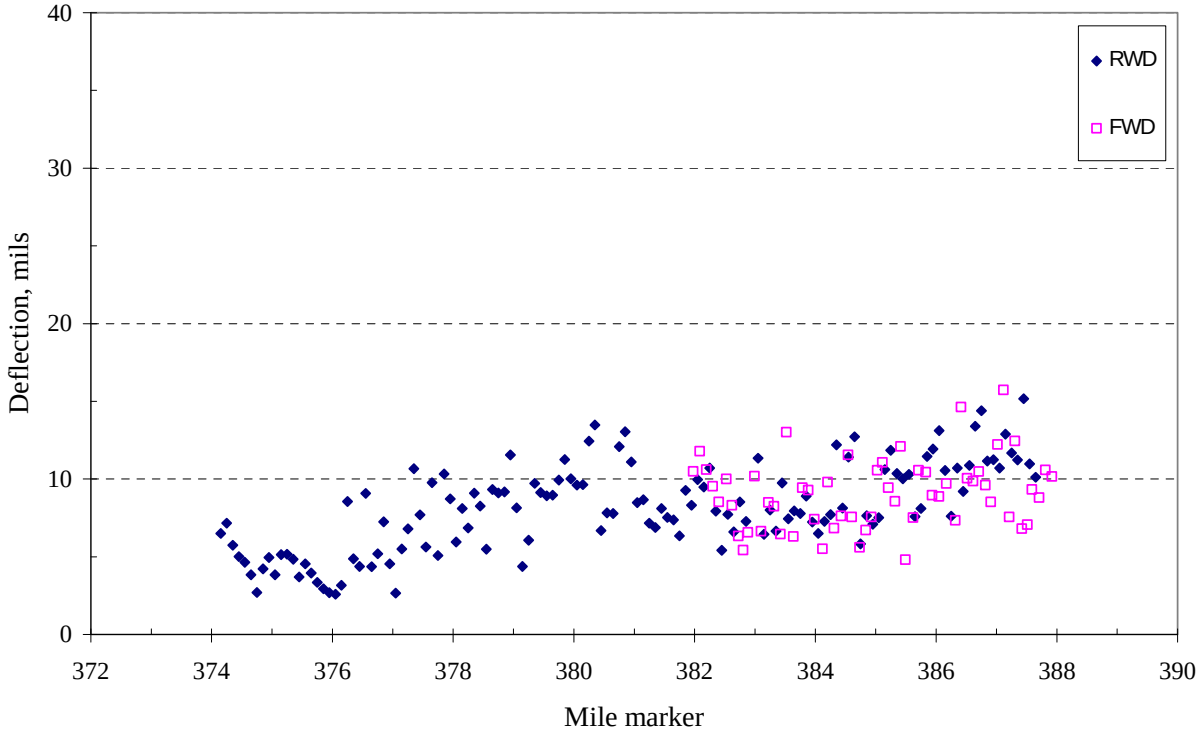
K 99.
US 56 to K 170 - southbound.



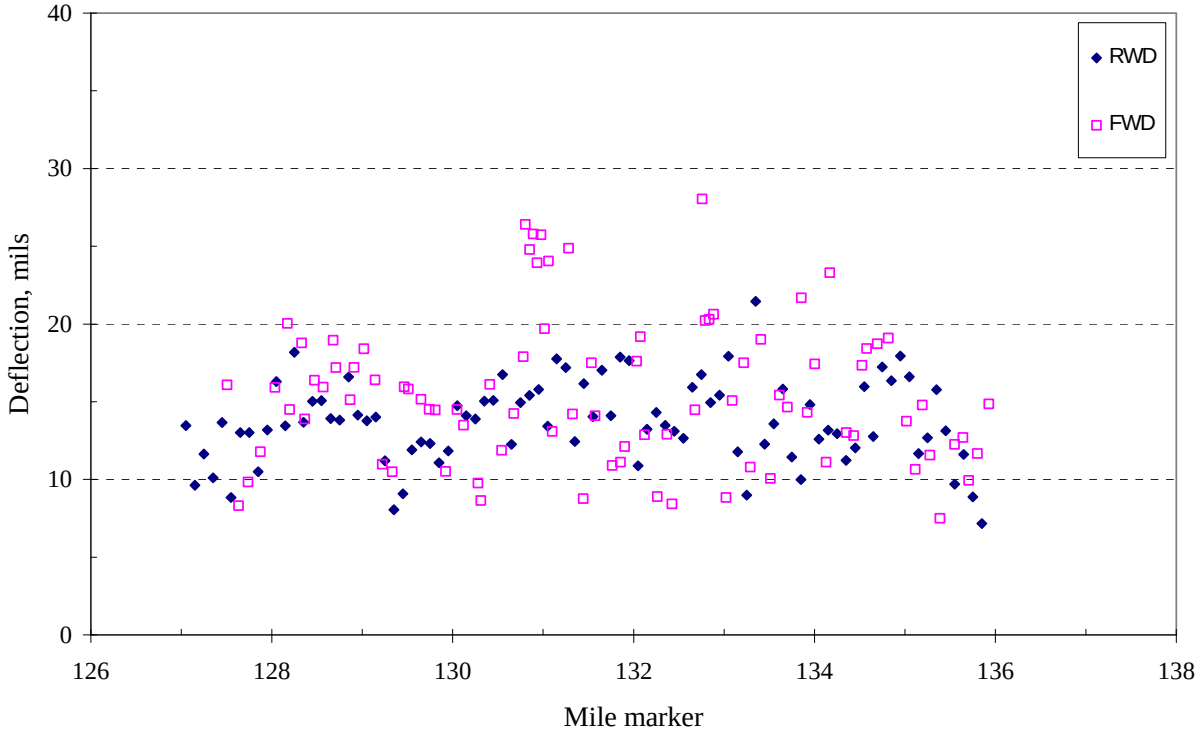
K 170.
K 99 to US 56 - eastbound.



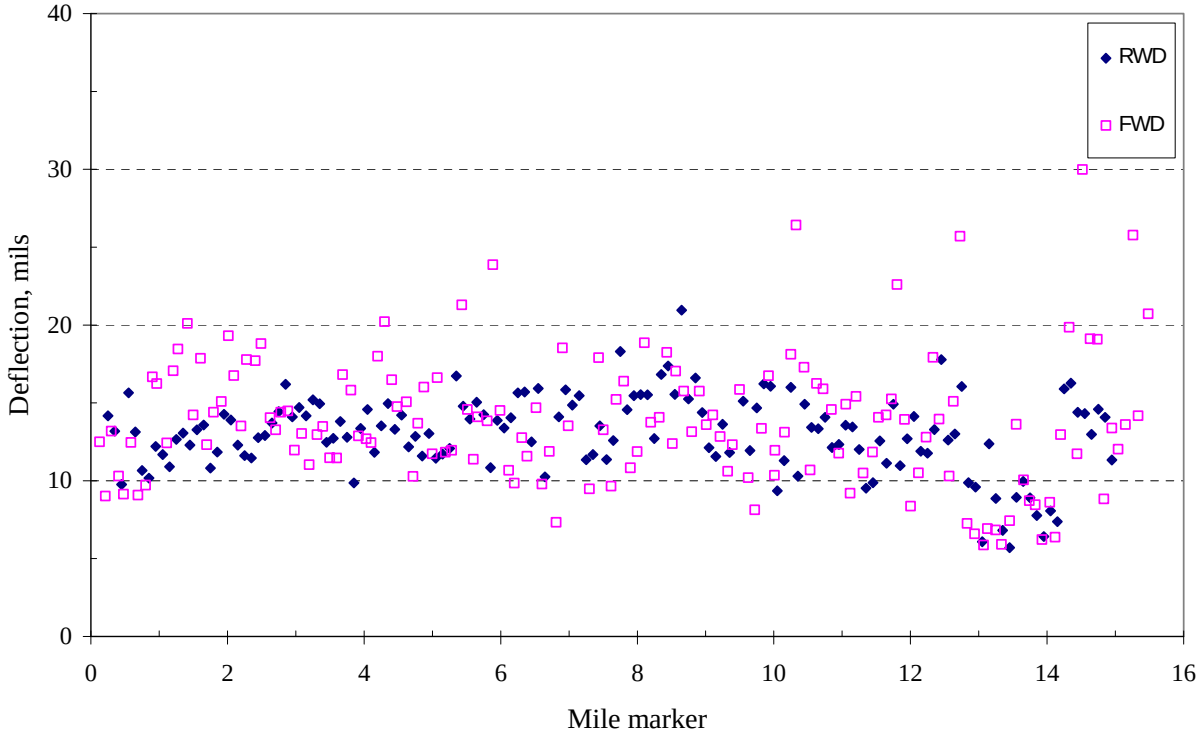
US 56.
K 170 to K 99 - westbound.



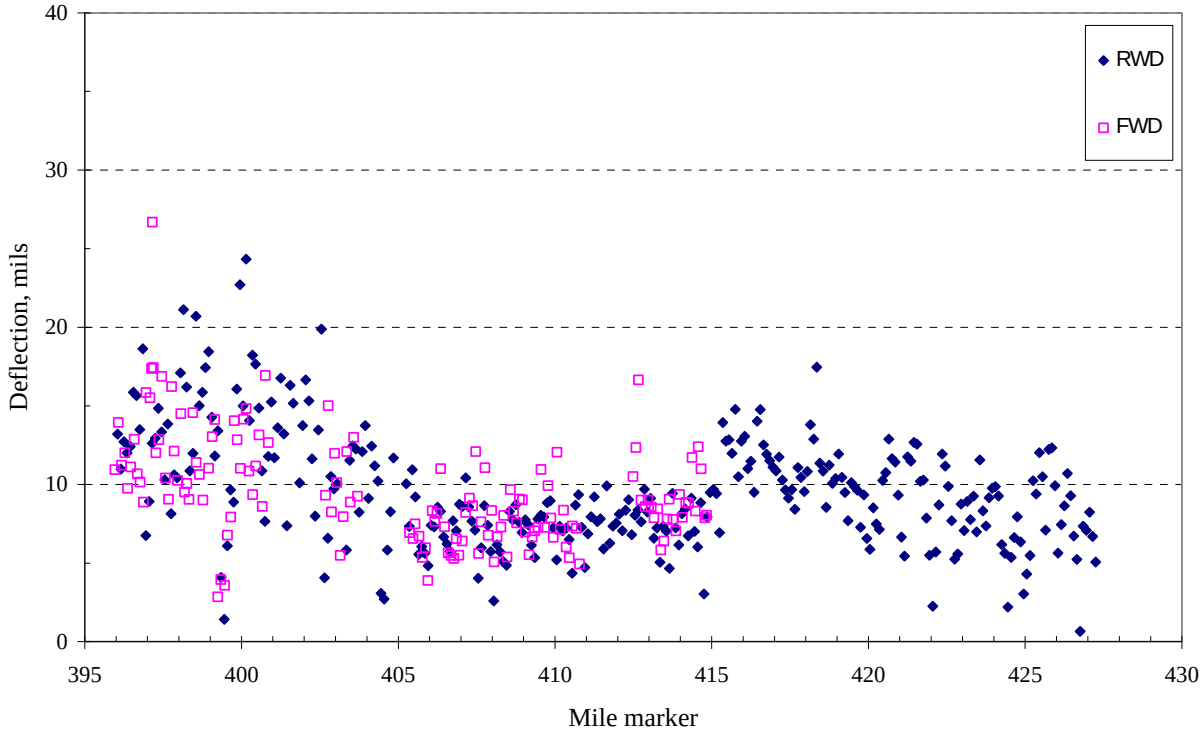
K 99.
US 56 to K 31 - northbound.



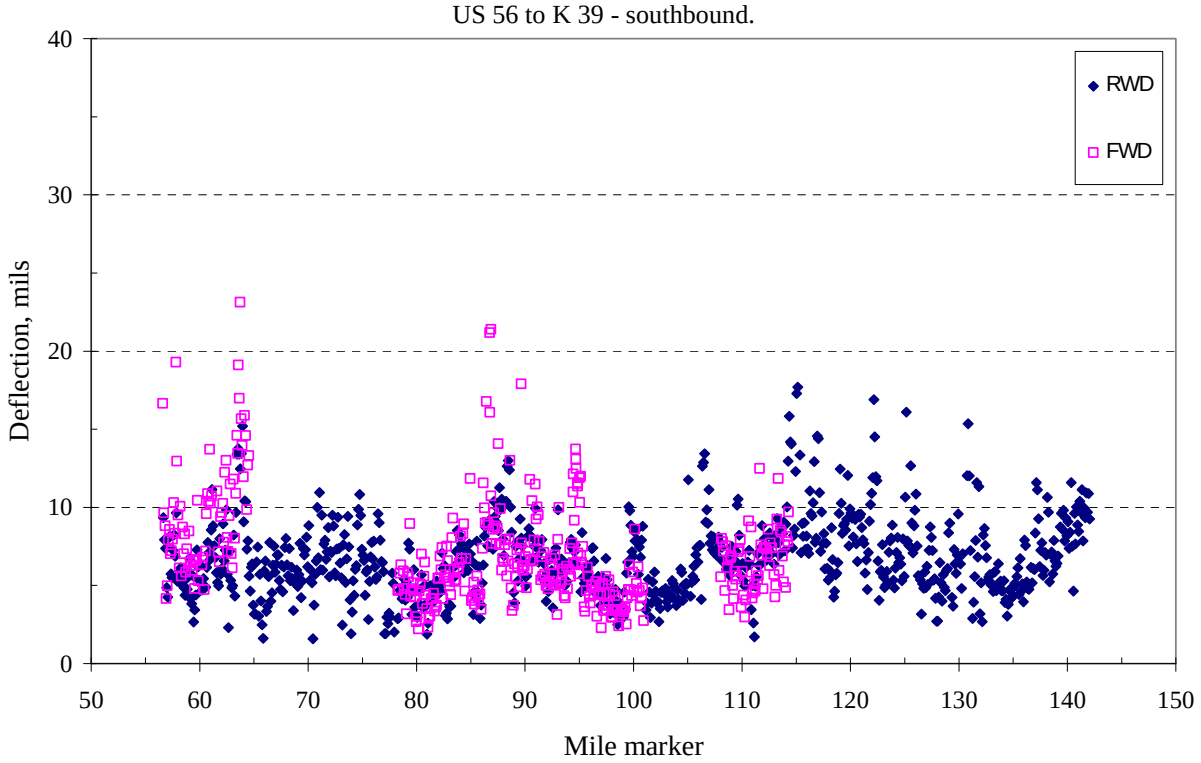
K 31.
K 99 to US 56 - eastbound.



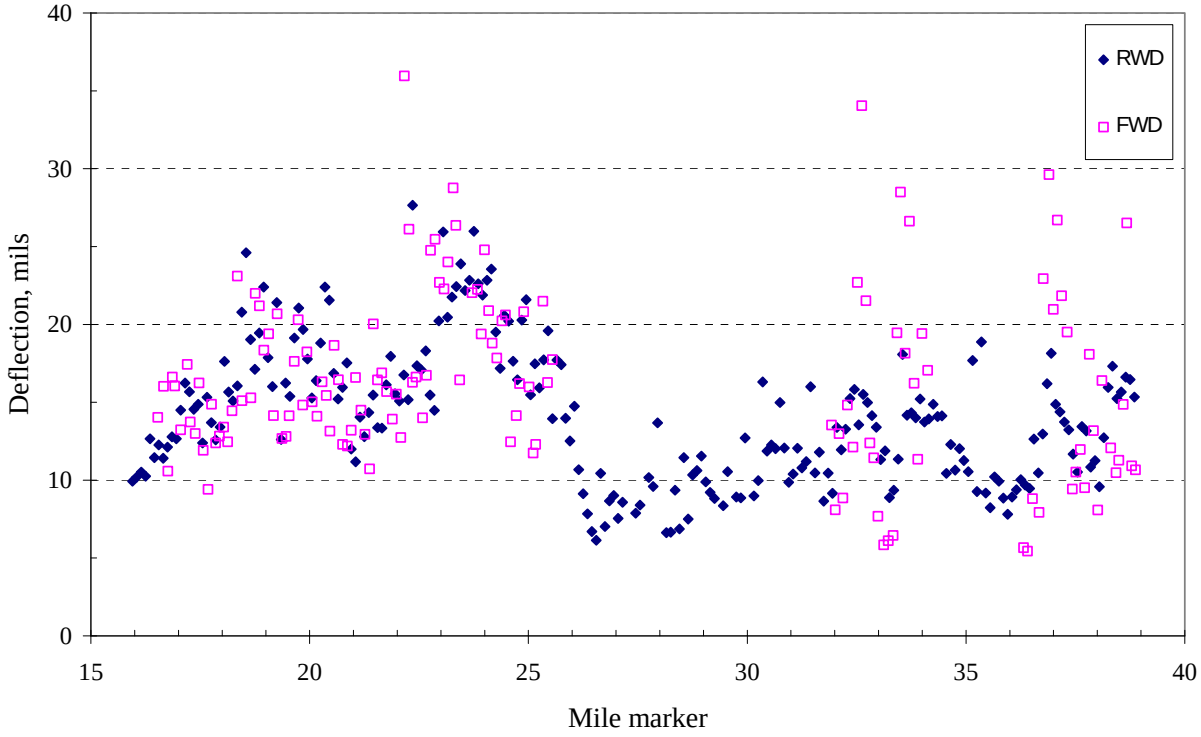
US 56.
K 31 to US 59 - eastbound.



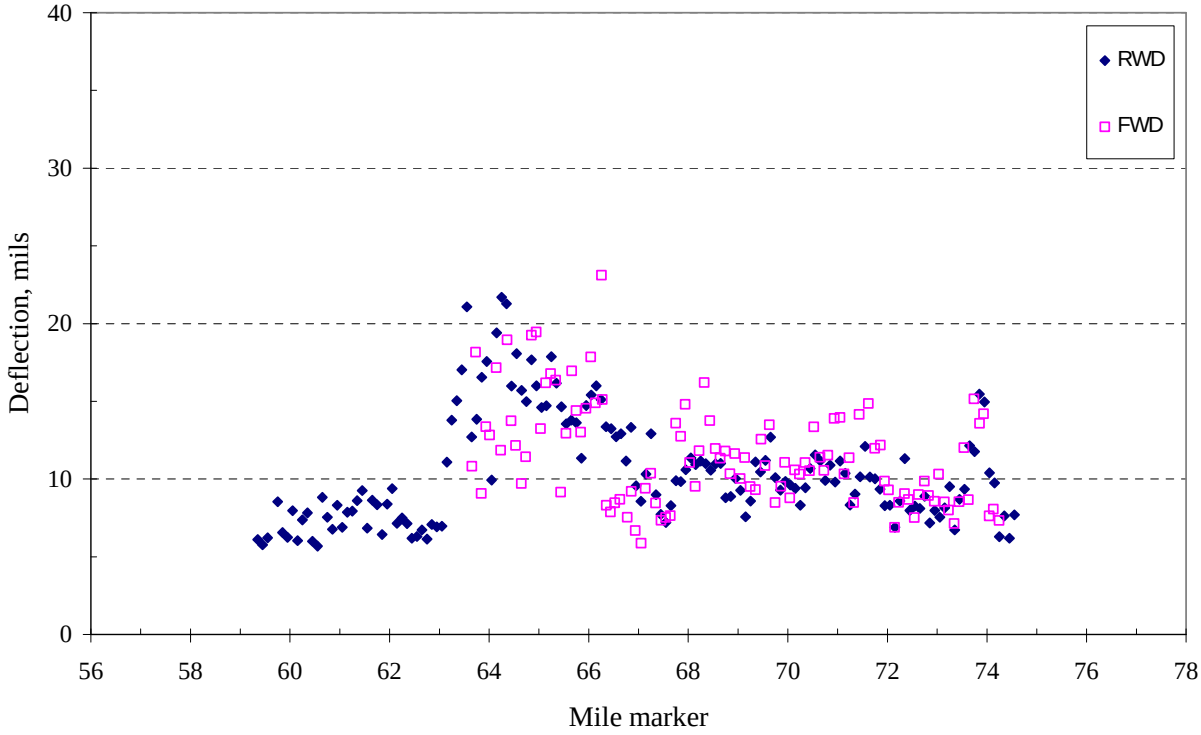
US 59.
US 56 to K 39 - southbound.



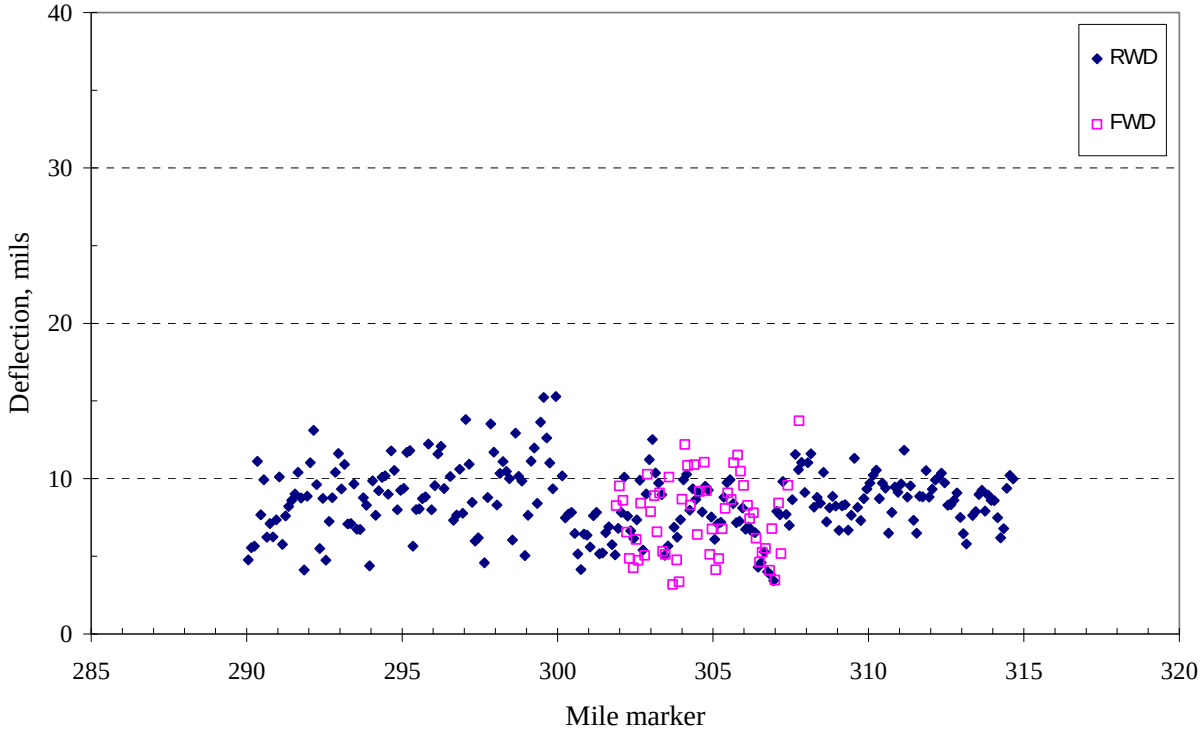
K 39.
US 59 to US 75 - westbound.



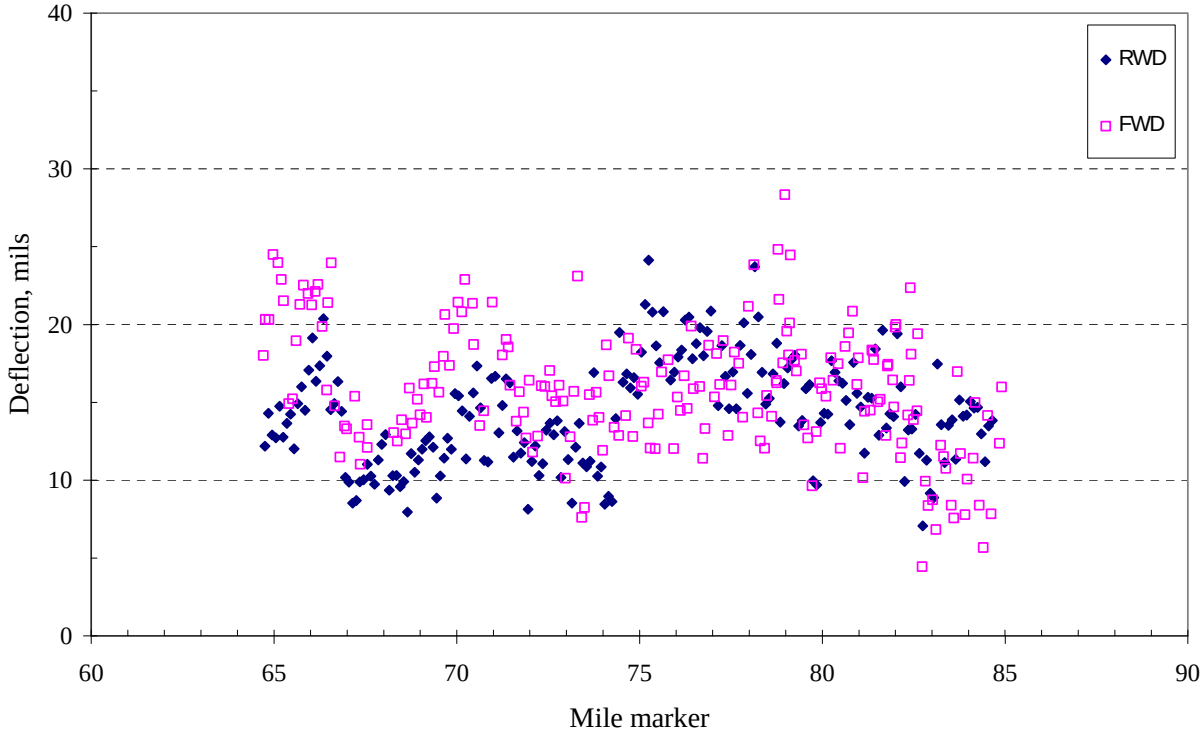
US 75.
K 39 to US 54 - northbound.



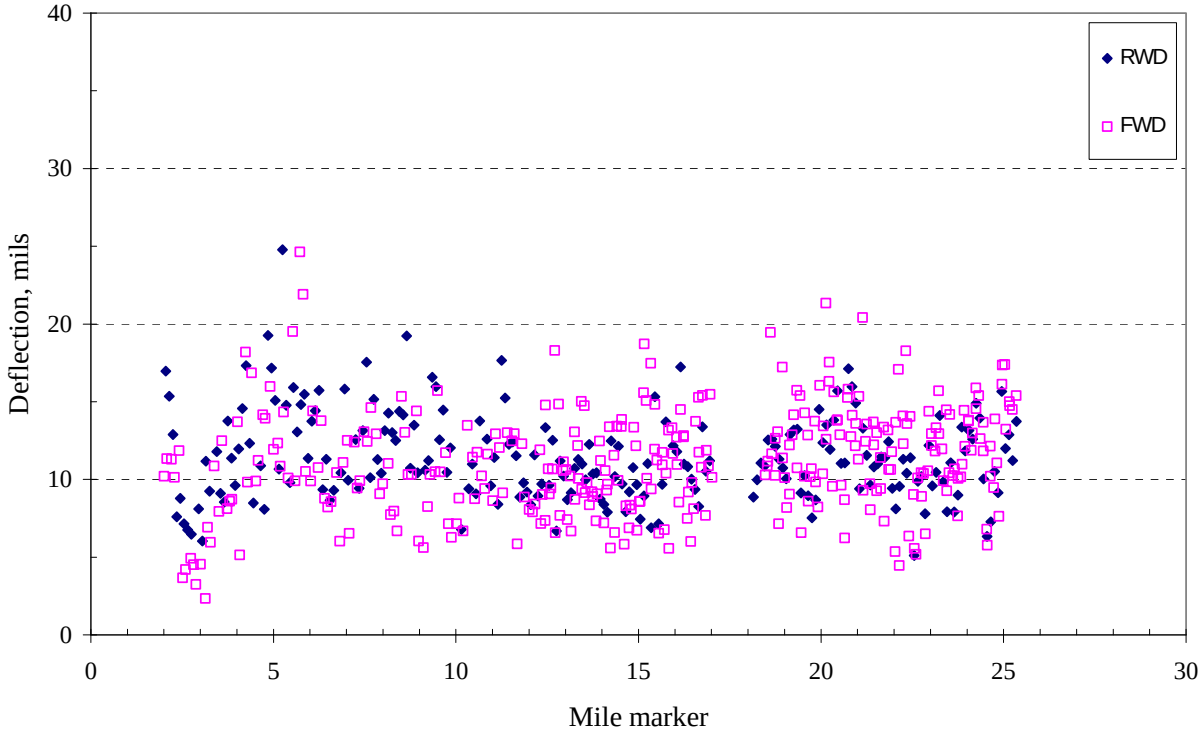
US 54.
US 75 to K 99 - westbound.



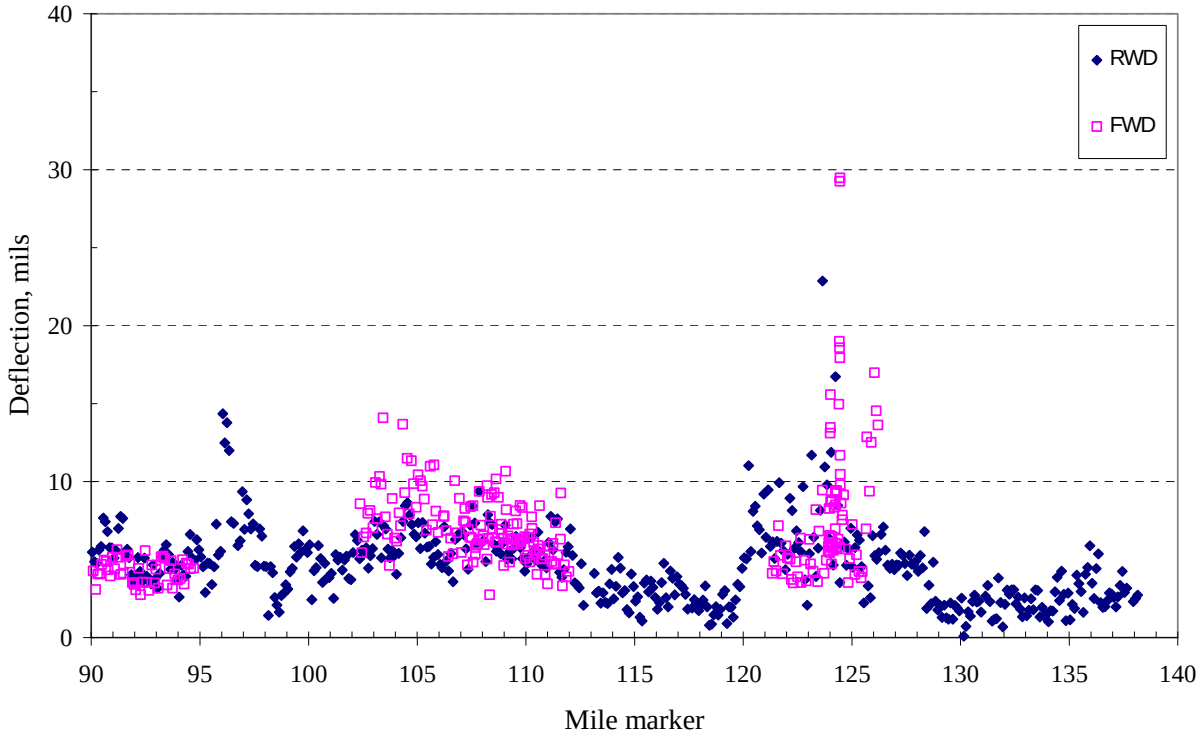
K 99.
US 54 to K 58 - northbound.



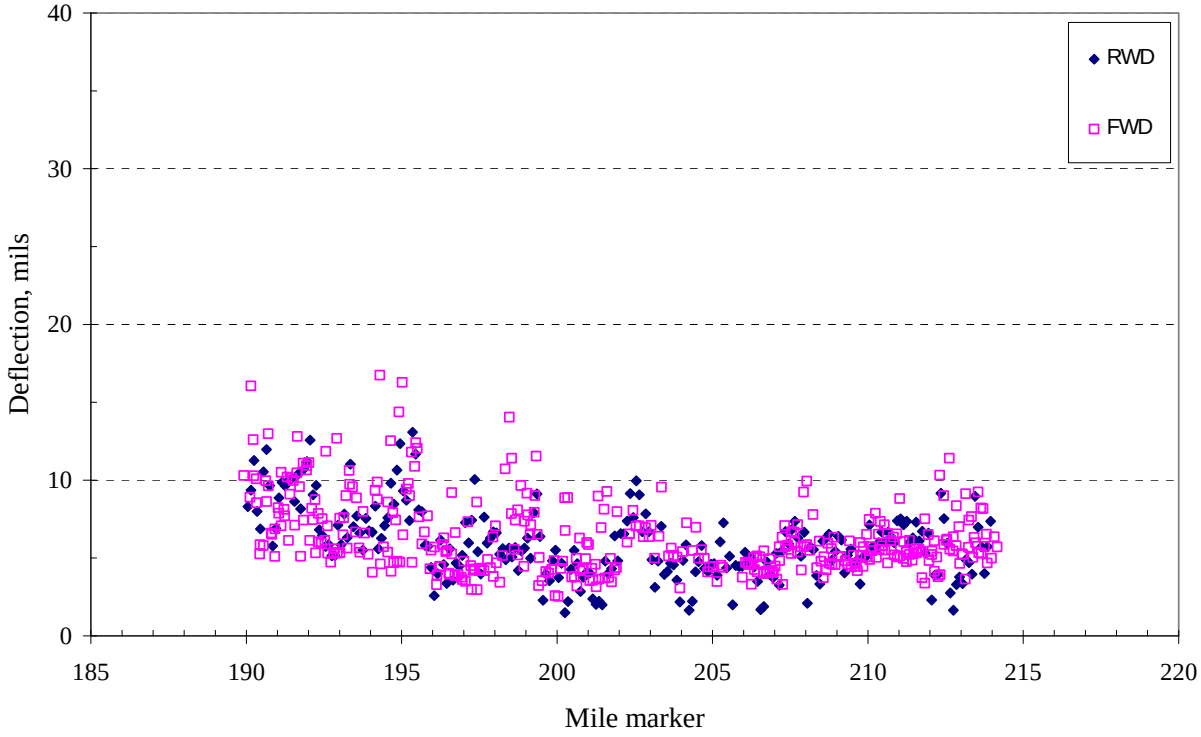
K 58.
K 99 to US 75 - eastbound.



US 75.
K 58 to US 56 - northbound.



US 75.
Holton to Sabetha - northbound.



APPENDIX B

RWD Dimensions and Weights

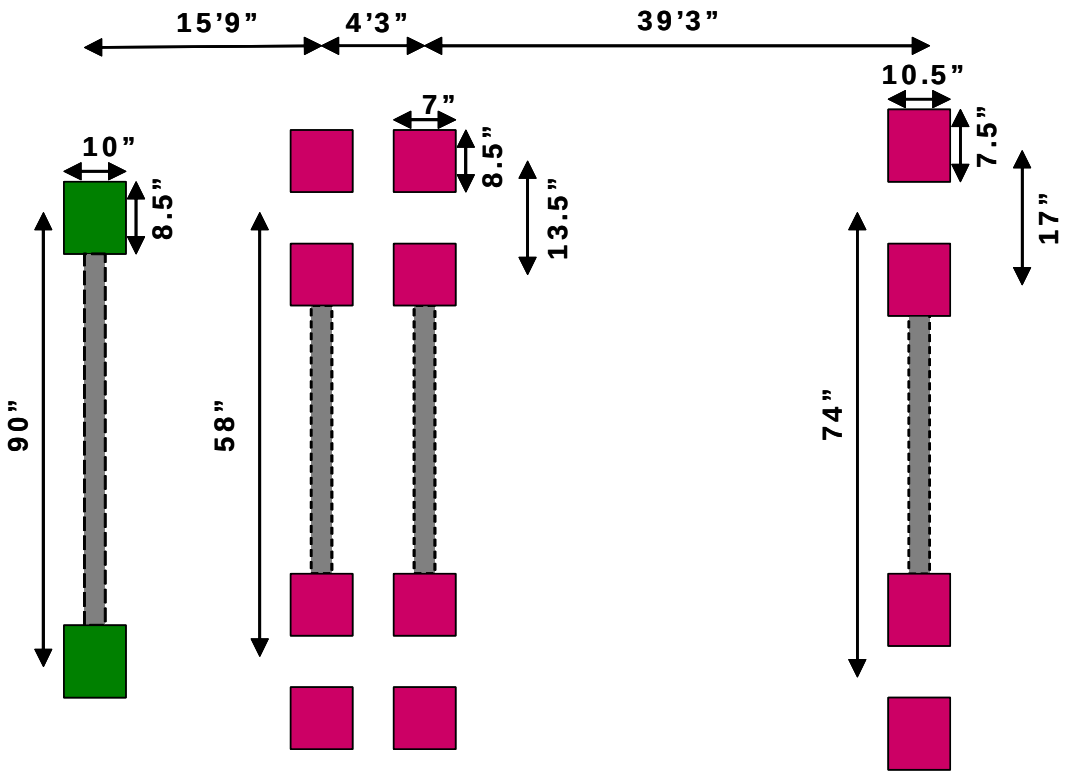


Figure B.1. RWD wheel configurations.

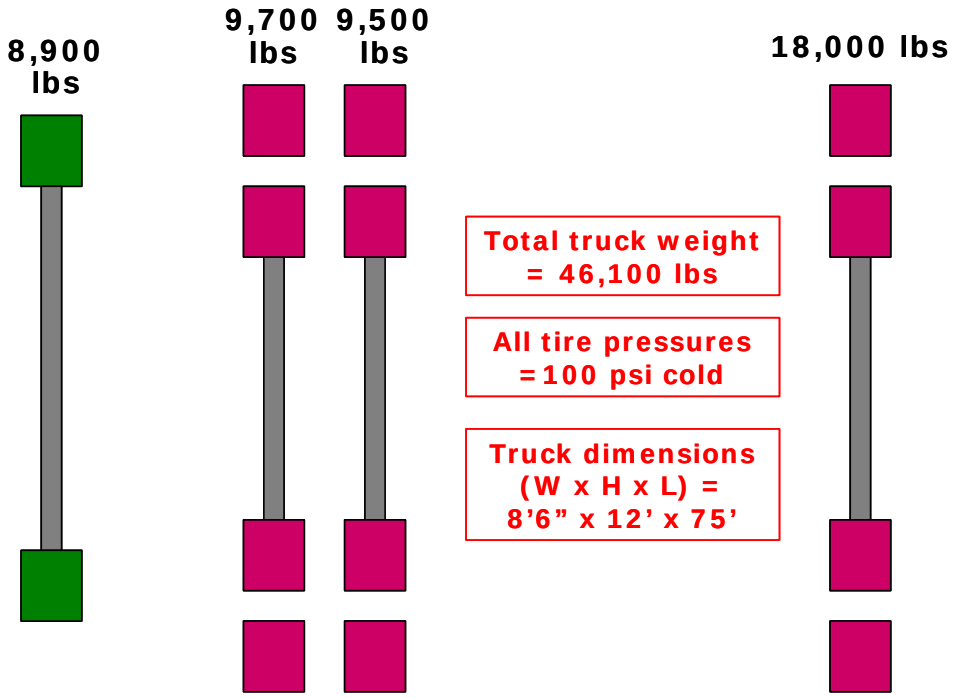


Figure B.2. RWD wheel loads.

Figure B.3. Weighing the RWD with portable scales on-site.

Figure B.4. Data acquisition equipment for the instruments – KSU.

APPENDIX C

Sabetha Instrument Data

Table C.1. Pressure data.

Section	Run	Offset	Value 1	Value 2	Value 3	Value 4	Value 5
Sec. # 1	1	11.32075	0	0.115557	1.199967	0.020328	
	2	9.669811	0.7176	0.127092	1.195482	0.034428	1.547733
	3	9.320755	0	0.143211	1.072875	0.033972	1.233207
	4	10	0	0	1.072782	0.032688	1.258293
	5	7.990566	0.624936	0	1.084047	0.034887	1.260126
Sec. # 2	1	15.66038	0	0.233676	1.488765	0.060525	
	2	18.66038	0.879762	0.143943	1.568337	0.064005	2.053542
	3	19.32075	0.860076	0.167472	0	0.037356	1.953093
	4	14.33019	1.027641	0.245031	1.59663	0.067392	1.999977
	5	13.33019	1.077636	0.254643	0	0.066201	1.969485
Sec. # 4	1	19.32075	0.400233	0.108321	0.798909	0.034794	1.022145
	2	12.66981	0.433929	0.111801	0.707802	0.030675	0.986709
	3	20.66981	0.406185	0.098157	0	0.023898	
	4	19.33962	0.398862	0	0.753678	0.021885	1.07022
	5	18.66981	0.421386	0.104019	0.772722	0.026463	1.027275

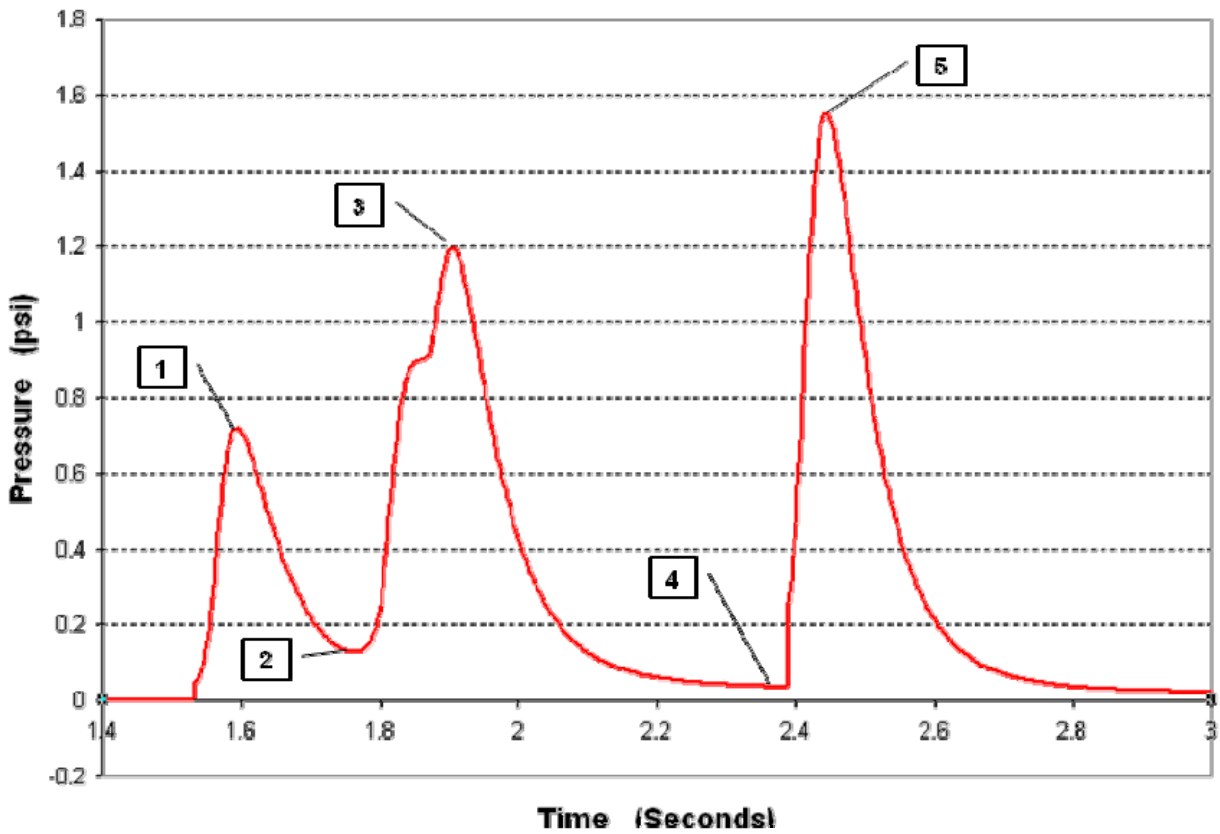


Figure C.1. Critical points in the pressure data trace.

Table C.2. Longitudinal strain data.

Section	Sensor	Run	Offset	Value 1	Value 2	Value 3	Value 4	Value 5	Value 6	Value 7	Value 8	Value 9	Value 10	Value 11
Section # 1	3	1	10.22642	-3.4	9	-4	0	0	0	-4.6	-1	-7.2	18.6	0
		2	9.943396	0	0	-4.6	6.8	2.4	8	-4	-0.6	-6		0
		3	8.226415	0	0	-2.8	6.4	1.4	5.8	-4.4	-1.6	-7.2		-5.2
		4	10	-2.8	6.2	-4.6	0	0	0	-3.8	-2.6	-8		-6.6
		5	7.169811	-2	6.8	-3.8	0	0	0	-2.8	-0.6	-5.8		-4
	7	1	8.226415	-3.8	13	-6.8	10.6	6.2	12.4	-6.6	-1.6	-8.8		-8.8
		2	2.943396	-2.8	11.8	-6	9	5.8	10.4	-5.2	-1.8	-7.8	23.2	-7.6
		3	6.226415	-2.2	9.4	-4.6	8	6.2	9.8	-5.4	-2	-7.4	19.4	-5.8
		4	4	-3	8.4	-5	7	5.2	8.8	-6	-2.4	0	18	-6
		5	4.169811	-2.6	9	-4.6	7.8	6	9.8	-5	-2.2	0		-5.6
Section # 2	4	1	15.33962	-5.2	0	-9	10.8	3.6	14.8	-2.4	0.4	-16.8	29.8	0
		2	18.33962	0	0	-12.2	9.8	1	14.6	-3.6	-1	0		-4.2
		3	18.67925	-8.2	11.2	-11.4	9.2	1.2	13	0	-3.6	-21.6	24.4	-7.2
		4	14.16981	-8.8	12.8	-10.8	10.8	2.4	14.4	-3.6	-1	0	25.4	-5.6
		5	16.67925	26.6	10.8	34.6	1.6	26.8	0	0	0	0		0
	5	1	10.66038	-7.2	15.4	-6.4	11.8	1.6	11.8	-5.8	0.4	-13.8	27	-6.2
		2	13.66038	-9.4	16.4	-10.6	11.8	-2	10.4	-8.6	-1	-17.4	27.2	-10.8
		3	15.32075	-9.4	14.6	0	0	-2.4	8.2	-10.4	-4	-19.6	23.4	0
		4	8.830189	-8.6	15.4	-7.2	12.4	0.4	10	-7	0	-15.8	25.2	-9
		5	7.830189	-5.6	0	-5.6	13.6	0	12.2	-5.2	1.4	-14.2		0
Sec. #4	6	1	15.77358	-2.4	6.4	-2.6	5.4	1.8	7	-1.2	0	-5.8	14	-3.4
		2	6.056604	-2.8	7.6	-3.2	5.6	2.4	6.6	-2.6	0	0	12.8	-3.2
		3	14.0566	0	0	-3	6.8	3.2	8.4	-2.2	0.6	-5.8	13.8	-3
		4	12.11321	0	8.4	3	6.2	-3.6	7.8	-2.4	0.8	-5.6	14.6	-2.4
		5	12.0566	-2.6	8.6	0	6.4	3	8.2	-2.2	0.4	-6	13.6	-2.8

Table C.3. Transverse strain data.

Section	Sensor	Run	Speed	Offset	Value 1	Value 2	Value 3	Value 4	Value 5
Section # 1	3	1		10.22642	29	0	29.8	-2	26.2
		2		9.943396		8.8	32.4	0	
		3		8.226415	26.4	0	30.8	-1.2	
		4		10	25.6	8		-2	
		5		7.169811	25.2	7.4		-0.6	
	5	1		7.320755	35.4	10.2	36	0.8	34.6
		2		3.169811	25.6	7.6	28.8	0	34.2
		3		5.320755	21	8	23.8	1.2	29.8
		4		4	15.4	2.8	17.4	-2.4	
		5		3.490566	15.4	3.6	18.2	-1.4	
	6	1		7.773585	38.4	11.4	41.2	0.8	42.2
		2		3.056604	27.4	7.2	31.8	0	39.4
		3		5.773585	21.6	6.4	27	-1	35
		4		4	18.8	4.6	22.6	-2.4	
		5		3.830189	18.6	4.6	22.6	-2.4	
	7	1		8.226415	37.6	11.8	42.4	0.8	41.2
		2		2.943396	28.6	8.2	32	0	38.6
		3		6.226415	22	7.2	27.8	-1.2	35.4
		4		4	19.2	5	22.4	-2.4	33.4
		5		4.169811	19.6	5.8	24.2	-2.2	27.8
Section # 2	2	1		14.88679	44.2	0	50.8	-4	44.4
		2		17.88679		0	54.8	-2.8	
		3		17.77358	14.2	-3.2	51.2	-5.6	63.8
		4		13.9434		10	52.4	-5.2	
		5		12.9434	52.6	15.6	52.2	-4.8	41.8
	4	1		15.33962		0		0	
		2		18.33962		0		0	
		3		18.67925		0		0	
		4		14.16981	70.6	24.2	51.2	0.8	60.2
		5		13.16981	82.6	34.4	59	8	58.2
	8	1		11.33962	61.8	24.6	63.4	1.8	45
		2		14.33962	59	18.6		-5.2	46
		3		16.67925		19	58.8	-6.6	
		4		9.169811	66.4	25.6		4.6	49.8
		5		8.169811	63.6	22.8	63.6	5.8	53.4
Section # 4	4	1		18.22642	20.4	7.8	29.4	0.6	26.6
		2		12.9434	24	7.8	27.8	0	21.4
		3		20.9434	15.2	3.8	26.4	0	27
		4		19.88679	15.8	4		-0.8	
		5		18.9434	19.6	6.2	27.4	0	25.6
	8	1		16.67925	26.6	10.8	34.6	1.6	26.8
		2		5.830189	16.8	4	19.8	-2.2	26
		3		13.83019	27.8	11.4	34.6	0.8	26
		4		11.66038	26.6	10.8	33.4	1.8	25.4
		5		11.83019		11.4	34.4	1	26.6

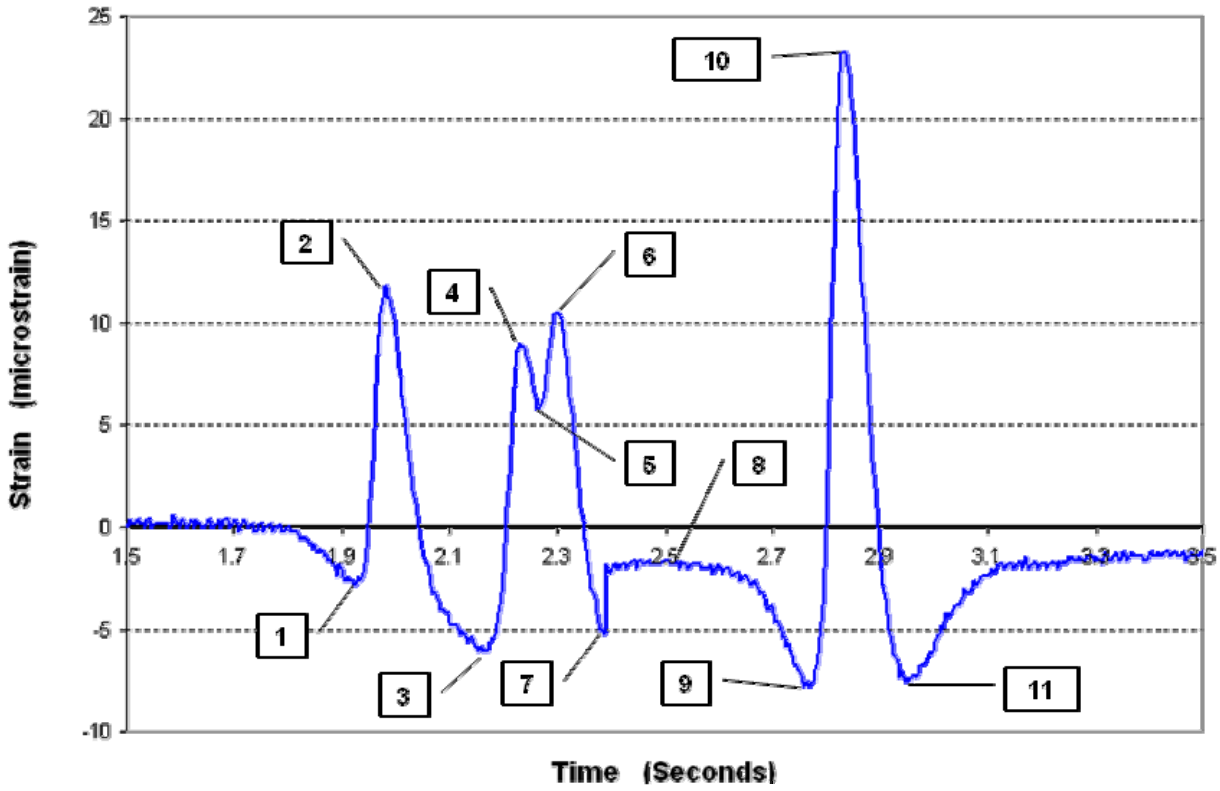


Figure C.2. Critical points in the longitudinal strain data trace.

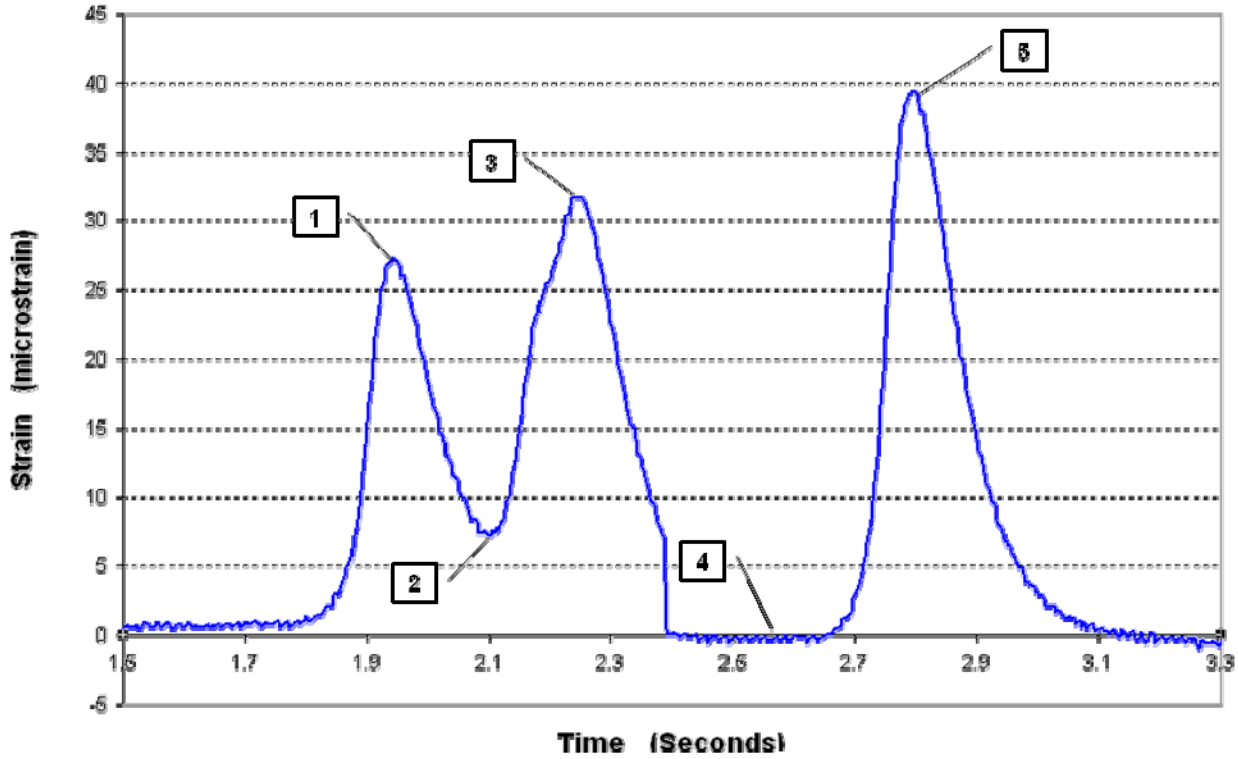


Figure C.3. Critical points in the transverse strain data trace.